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Geology of the Ramapo Fault System

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Introduction

On this trip we will examine exposures of igneous, metasedimentary, and sedimentary rocks of Precambrian, Paleozoic and Triassic age that crop out along the Ramapo fault system in New York State near the northern end of the Newark basin. Previously published material (cited in references) and unpublished data from recent Masters theses completed at City College by Susan Shuart and Vladimir Alexandrov will be discussed. In addition, ongoing studies by geology graduate students in the City College and by myself will be presented. Isotopic age studies by Ron Senechal (of Lamont-Doherty Geological Observatory), Dick Armstrong and Bruce Chai (of Yale) have contributed significantly to the results. This phase of the study is continuing. Because our current investigations are not completed, I hesitate to put our results in written form at present. These present studies deal largely with detailed petrographic and petrofabric examination of the different kinds of "mylonitic" rocks found in the fault zones from the north end of the Newark basin near Thiels, New York, northeastward across the Hudson Highlands.

We believe that different kinds of "mylonite" and cataclastic rocks formed during different movements on the fault.

Statement of Problem

Previous investigations by Shuart (1969), Ratcliffe (1970, 1971), and Ratcliffe and others (1972) have uncovered a body of evidence that indicates the downdropping of Triassic rocks along the Ramapo fault is just one of a series of movements on an old fracture system that was initiated in Precambrian time. The fault zone has been repeatedly reactivated since. The general term tectonic heredity has been applied (originally used by Don Wise) to this case where old fractures or folds have persisted through time and have had a direct influence on the nature of younger structures. It is my belief that once this fracture system formed in Precambrian time, it continued to be utilized in subsequent orogenic events. Similar fracture systems are known from the Canadian shield, East Africa and Australia. We should be prepared for the possibility that in continental areas a system of crustal imhomogeneities of great age and depth may be of extreme importance in controlling the response of continental rocks to stresses generated by plate tectonic or other orogenic mechanisms.

The geologic history of the Ramapo fault system as understood at present is given below: (1) late Precambrian, right-lateral faulting concomitant with intrusion of the Canopus pluton, followed by post-tectonic intrusion of the older part of the Rosetown pluton; (2) Early Ordovician block faulting with oceanward block moved down, erosion on the western block, producing the Middle Ordovician unconformity at Annsville; (3) renewed normal (?) faulting in Rosetown area and intrusion of diorities of younger part of the Rosetown pluton in the Middle to

Late Ordovician; (4) intense right-lateral transcurrent faulting in post-Middle Ordovician to pre-Middle Devonian time, producing cataclasis of Precambrian to Middle Ordovician rocks along fracture zone. This movement may have been in part synchronous with Taconic deformation and metamorphism in the adjacent Manhattan Prong; (5) Late Triassic rejuvenation of the old fracture system as a system of normal faults, producing the Newark depositional basin. Block faulting continued during the Late Triassic and possibly into the Jurassic.

The recent whole rock Rb/Sr and K-Ar isotopic study by Armstrong, Chai, Senechal (Ratcliffe and others, 1972) of the Canopus pluton has firmly established the Precambrian age (1032 ± 45 m.y.) (item 1 above) of the fracturing.

I have pointed out previously (Ratcliffe, 1970, 1971) that the long history of movement of this fracture system suggests strongly that the gneisses of the Hudson Highlands in this area are not allochthonous but have moved vertically and laterally during orogenies in the Paleozoic. Basement block fault tectonics of this kind might readily be applied to other fault systems, having similar trends elsewhere in the New Jersey and New York Highlands as well as to the chain of basement exposures from Newburgh northeastward to Stissing Mountain. I have little firsthand knowledge about these other localities but merely suggest this as an alternative (as others have done) to the allochthonous hypothesis. At several stops we will see exposures

of "mylonitic" rocks in the faults. For the sake of consistency, the nomenclature of Higgins (1971) for cataclastic rocks will be used. The terminology is given below.

Rocks with primary cohesion

Cataclasis cominant over neomineralization-recrystallization		Neomineralization-recrystallization dominant over cataclasis
Rocks without fluxion struction	Rocks with fluxion structure	Rocks with fluxion structure
Microbreccia	Protomylonite	Mylonite gneiss (mylonite schist)
Cataclasite	Mylonite	Blastomylonite
	Ultramylonite	

The progression protomylonite, mylonite, ultramylonite will be of particular importance. In addition, we will visit an exposure of possible pseudotachylite (pseudo-pseudotachylite??). Higgins (197k, p. 21) defines pseudotachylite as:

> "A glassy rock generally resembling tachylite, commonly of instrusive habit, and closely associated with faults or fault zones. The groundmass of the rock is composed mainly of glass, which in some cases contains microlites of feldspar, vesicles, spherulites, amygdules, or partially melted rock and mineral fragments. The rock fragments may be cataclastic or undeformed. Pseudotachylite probably forms by melting resulting from frictional fusion during faulting of already-hot rocks."

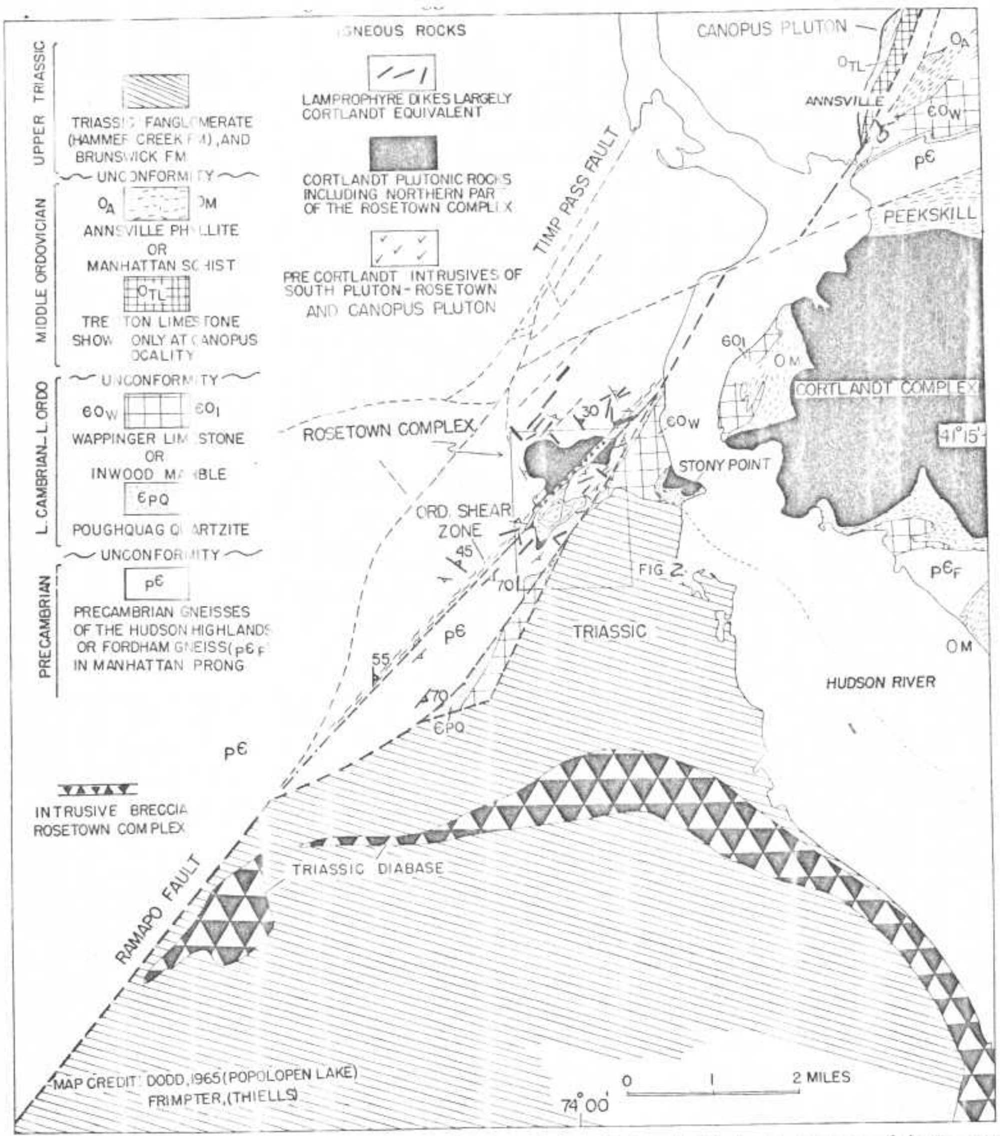

Figure 1 Generalized geologic map of the northern end of the Newark basin, showing the relationship of the Ramapo fault system to the Rosetown and Canopus plutons. Heavy lines signify faults of the Ramapo fault system; fine dashed lines other high-angle faults in the Hudson Highlands (fault patterns west of the Ramapo fault *from* Dodd, 1965, [Popolopen Lake quadrangle] and Frimpter, 1967). See Figure 2 for location of quadrangles.

Figure 1. Modified from Ratcliffe, 1971. Note marble in Canopus area shown as Ordovician now thought to be largely of Precambrian age (see Ratcliffe and others, 1972).

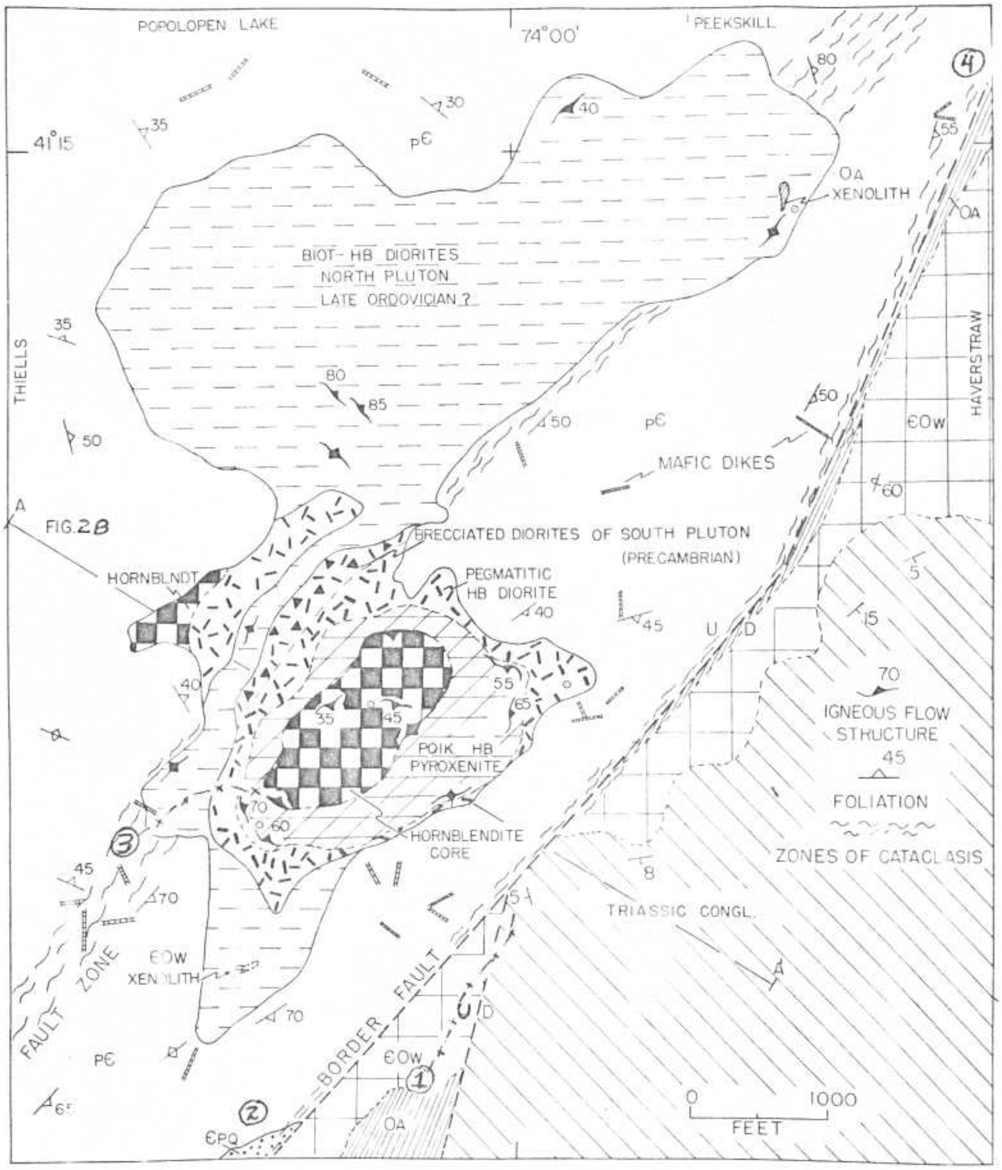

Figure 2A Generalized geologic map of the Ramapo fault at the northern end of the Newark basin near Stony Point, showing the location of the Rosetown pluton and line of section shown on Figure 4. Numbered localities are referred to in text. Explanation: p€, Precambrian granite gneiss; €pQ, Poughquag Quartzite; €OW, Wappinger Limestone; OA, Annsville Phyllite. Igneous units identified on map. Geology mapped by Ratcliffe, 1967-1970; and Shuart, 1968-69.

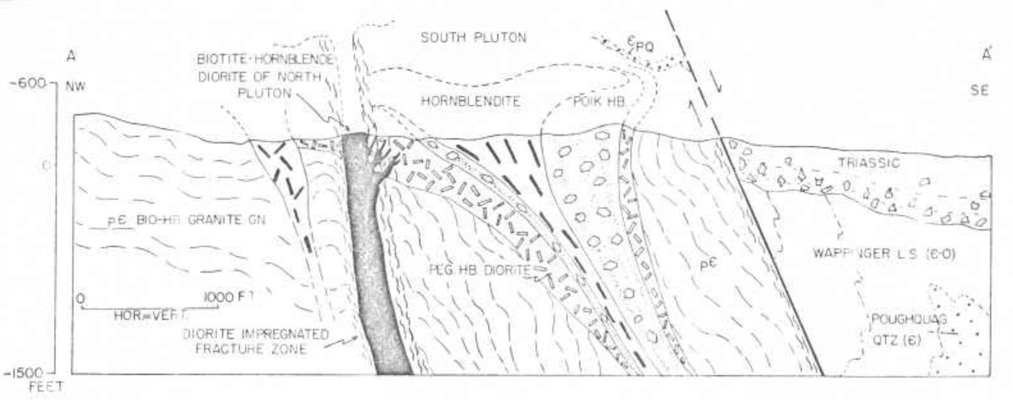

Figure 2B Profile and section of the Ramapo fault in the vicinity of the Rosetown pluton, showing the offset of the Paleozoic rocks and the Late Ordovician fault zone into which diorites of the younger part of the Rosetown pluton intrude. See Figure 2A for line of section.

Figure 2 A and B. Taken from Ratcliffe, 1971. Stops shown on map.

Field trip stops.

Each of the stops is on Figure 2 or 3.

Stop 1.

Thiels quadrangle intersection Geotschius Bridge Rd. (elev. 156 ft.) and unnamed road south of Cedar Brook. Exposures of Wappinger Limestone (Ꞓ-O) and Annsville Phyllite (ordovician) near Ramapo fault. Hills to west Collaberg Mt. are Precambrian gneisses overlain unconformably by SE dipping Poughquag Quartzite (Stop 2). Triassic rocks crop out to the east. Frimpter (1967) interpreted this wedge of Paleozoic rock as a horst bounded east and west by faults. I agree, but the faults probably are not of the same age. The easterly one may be Triassic, the western one Pre-Triassic. Walk about 800 feet north to reservoir and dam exposure of Triassic fanglomerate in bed of Cedar Pond Brook. Exposures of ultramylonite and pseduotachylite, can be seen by the shore of the pond. This probably formed form granulation of Precambrian granitic gneiss rather than from the Annsville Phyllite.

Stop 2.

Poughquag Quartzite - Precambrian unconformity. Exposures at approximately 350 feet on southeast flank of Collaberg Mt. This is a recently discovered exposure of some significance. It demonstrates that at this point the Paleozoic-Precambrian contact is right-side-up. Therefore, if the Hudson Highlands are allochthonous, the

upper limb alone is represented. No hammers please! Note the impure basal conglomerate and the clean quartzite. Float of quartzite lower down on the hill has a distinctive flaser texture suggestive of cataclastic deformation. We are near the western fault, Fig. 2.

Stop 3.

Igneous rocks of the Rosetown pluton (see Figure 2). Stop at Cedar Pond Brook and Rt. 210 to see exposures of cataclastically deformed p€ gneiss intruded by lamprophyre dikes and diorite of the younger part of the Rosetown pluton. Downstream are exposures of hornblendite, hornblende pyroxenite in the core of the Precambrian part of the Rosetown pluton and intrusive breccia shown on Fig. 2. Hornblende from this funnel shaped pluton gives K-Ar ages of 810 ± 8m.y., and 790 ± 10 m.y. (see section Fig. 2B).

Stop 4.

Roadcut of Precambrian gneiss, near fault at Tomkins Cove (Haverstraw quadrangle. (See Fig. 2A) Small veinlets of pseudotachyltic (?) crosscut cataclastic matrix in proximity of fault. Exposures to east at 9W are Annsville Phyllite and Wappinger Limestone. This black veined rock is not found to the north in any fault zones and it appears this kind of mylonitic-cataclastic rock is geographically linked to areas of possible Triassic movement. Perhaps these rocks were generated under high strain rates at shallow crustal levels, wheras the other mylonites formed under plutonic-metamorphic conditions, during more ancient faulting.

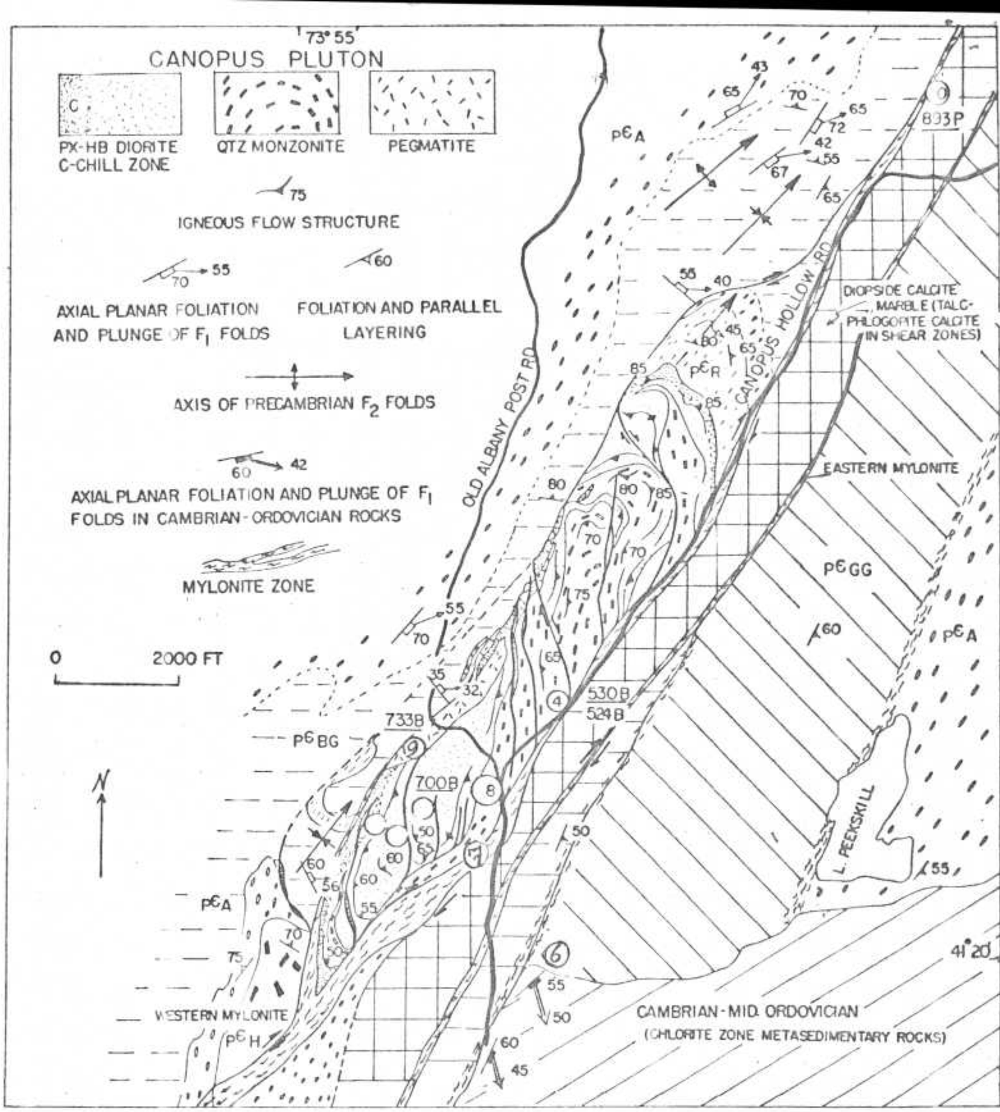

Figure 3 Generalized geologic map of the Canopus pluton, showing internal igneous flow structure and relationship of pluton to F_1 and F_2 structure in Precambrian gneisses. Key to Precambrian lithologies: p€A = amphibolitic gneiss, p€GG = granodioritic gneiss, p€BG = biotite quartz plagioclase paragneiss, p€R = rusty weathering granitic gneiss, p€H = hornblende-biotite granitic gneiss. K-Ar and Rb-Sr ages are shown on map. (B = biotite, P = phlogopite).

Underlined dates refer to K-Ar, other date Rb-Sr

Figure 3. This map taken from Ratcliffe and others, 1972. Western mylonite believed to be Precambrian, eastern one Ordovician. Stops 6, 7, 8, 9, and 10 are shown on map.

Stop 5.

Sand pit at Annsville, New York. Peekskill quadrangle. (See Fig. 1) This excellently exposed fault zone as well as others in this valley is being studied by Richard Feuerstein, a Masters student at City. Rich is hoping to ascertain the mineralogic and structural characteristics of the mylonitic rocks exposed in the Canopus Valley. The previous work has demonstrated faulting of Precambrian and post Middle Ordovician age. There is little evidence for any Triassic faulting. Mylonitic rocks of two different ages may be exposed in this sand pit.

An upper fault, traceable in a N.35°E. direction at the base of the dark Annsville Phyllite has a distinctive 5-10 foot thick zone of mylonite at its base. This contact truncates N.5°E. trending mylonite zones up to 50 feet thick developed in the Precambrian gneisses exposed in the lower part of the exposure. The mylonite zones in the Precambrian are of probable Precambrian age.

Small crops of Wappinger limestone can be seen near the northern end of the exposure, as well as a tectonic inclusion of retrograded, talc, serpentine tremolite-actinolite p€ marble. Precambrian calcite marble containing woolastonite,dioside, grossular garnet, and calcite crops out 2,000 feet north of this exposure where inclusions of Annsville Phyllite and retrograded Precambrian rocks are tectonically interleaved.

We believe the fault textures and structures found here are more consistent with strike-slip faulting than with normal faulting.

Crystallization of biotite porphyroblasts across the mylonitic fabric of the younger mylonite (beneath the Annsville) suggest the faulting is not of Triassic age because metamorphic conditions are not known from this area in Triassic or younger time. THEREFORE WE CONCLUDE THAT THE EXTENSION OF THE RAMAPO FAULT, NORTH OF THE HUDSON RIVER IS NOT OF TRIASSIC AGE BUT PROBABLY OF LOWER PALEOZOIC AGE.

Stop 6.

Exposure of Annsville Phyllite, Wappinger Limestone, and Poughquag Quartzite Peekskill quadrangle at south side of small pond 600 feet east of intersection of Gallows Hill Road and Sprout Brook Road. This exposure was first shown to me by Andy Ohan, who did a Masters thesis in this area at N.Y.U. Here a thin sequence of Wappinger is exposed beneath the Annsville. The total section from Annsville down to basement may be as little as 150-200 feet. If the fault seen in the sand pit at Stop 5 is a normal fault, the displacement probably is very slight (240-300 ft.) because the Paleozoic rocks dip 35°-50° SE and are truncated by the nearly vertical fault. Mylonitic rocks can be seen at the northwestern end of the lake marking the extension of the fault seen in the sand pit.

Stop 7.

Blastomylonite - western side of Canopus Valley at Continental illage, New York. Sheared igneous rock and gneiss in Precambrian fault zone.

Stop 8.

Igneous rocks of the Canopus pluton. This is a Precambrian diorite-monzonite pluton that appears to have been intruded during acting movement on the fault zone marking the western side of the Canopus Valley. Stop location (sample site 8) in Figure 3. Excellent exposures of the monzonite part of the pluton and the transition to pyroxene diorite can be seen on the slopes above the road. North on the right fork are fresh exposures of the coarse grained monzonite (locality 4, Figure 3).

Stop 9.

Figure 3. Coarse grained biotite pegmatite, intruded into the western fault zone. K-Ar age of biotite is 733m.y.

Stop 10.

Coarse grained Precambrian marble Canopus Valley - locality 10, Figure 3. Phlogopite from sheared marble at this locality gives a K-Ar age of 893 m.y., thus establishing the Precambrian age of the marble.

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The Geomorphology of Northern New Jersey and Part of Eastern Pennsylvania. A Field Trip Guide.

by

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ROUTE DESCRIPTION

Cumulative
Mileage

0.0 Starting Point. New Jersey route 17 proceeding North from Ford Sales and Service in Rutherford. En route pass outcrop of Triassic Brunswick formation in parking lot of the Fiesta Catering Company in Wood-Ridge.

4.8 Turn left (W) onto U. S. Route 80.

11.5 Turn right (N) at Main Street Paterson exit.
Turn left (W) onto Grand Street Paterson.
Turn left (S) onto New St. Paterson over overpass on U. S. Route 80.
Proceed to Garret Mt. Reservation.

14.1 STOP ONE: LOOKOUT AT GARRET MOUNTAIN RESERVATION

We are now on the NE to SW trending First Watchung Mountain. It is the outcrop of an extrusive sheet which is more resistant than the Triassic sediments. It has a gentle western dip slope and a steep eastern scarp slope.

Immediately to the North East is the Paterson gap almost two miles wide. On a very clear day we can see the Sparkill Gap in the Palisades. While to the west there is a similar wide gap in the Second Watchung Mountain. According to the interpretation by Douglas Johnson the ancestral Hudson River was superimposed through Cretaceous coastal plain sediments onto these ridges forming water gaps in them. This is known as the theory of superimposed subsequent drainage. SEE FIGURE 1 discussion of evidence supporting this interpretation.

Retrace route to Grand St. Paterson. Turn left (W) on Grand Street which continues into Dixon Ave. Turn left (S) at light on Glover Street. Turn right (W) on Nagle Street to U. S. Route 80 West.

17.0 Point of return to U. S. Route 80 West.

20.4 Turn right from U. S. Route 80 West at exit to N. J. Route 23 south toward Verona. Turn left (E) onto Bloomfield Ave. Proceed a few hundred feet to right turn and then left into parking lot at overlook, Mountclair Wind Gap.

26.8 STOP TWO: OVERLOOK AT MOUNTCLAIR WIND GAP IN FIRST WATCHUNG MOUNTAIN

On a clear day one can see the skyscrapers of Manhattan Island from here. The Empire State Building is eighteen miles away. Manhattan island is on the Manhattan prong of the New England Upland Province. Note the narrow Montclair Wind Gap. According to the interpretation by Douglas Johnson, a west flowing obsequent stream starting at the Cretaceous coastal plain cover was superimposed over the First and Second Watchung Mountains forming gaps in them. Later on subsequent streams flowing on the nonresistant Triassic sediments captured segments of the obsequent forming wind gaps. SEE FIGURE 2 Study Chart 1.

30.2 STOP THREE: CALDWELL (MOMENTARY STOP)

Proceed west on Bloomfield Ave. (N.J. Route 506) to Caldwell located on on the Second Watchung. The Caldwell Wind Gap cannot be seen because of building construction in Caldwell. Look West over the basin of the former glacial Lake Passaic. Fine grained shore deposits of this lake were excavated in the construction of many buildings in western Caldwell.

From the roofs of apartment houses here one can see the low form of the Third Watchung (Hook Mountain) in the lake basin and the western shore of the lake at the border of the Readiing Prong of the New England Upland province, ten miles away.

Continue west on Bloomfield Avenue (N.J. Route 506) down onto the level floor of glacial lake Passaic.

32.9 Junction with U. S. Route 46 West.

33.7 STOP FOUR: HOOK MOUNTAIN (THIRD WATCHUNG RIDGE)

Leave U. S. Route 46 on Hook Mt. Road but park immediately at the base of Hook Mt. right next to Route 46. Hook Mountain, also a west dipping extrusive sheet, is much narrower than the other two Watchungs and therefore has not been able to maintain its height. (200' to 300' as opposed to 400' to 800' thick).

The gap here in the third Watchung between Hook Mt. and Riker Hill is the fourth gap starting with Sparkill Gap formed by the superimposed subsequent Hudson River according to the interpretation by Douglas Johnson. Note the escarpment of the Reading Prong six miles to the West. The Triassic sediments were faulted down against the Precambrian metamorphic rocks at this point. If we follow the concept of Schooley peneplanation during Tertiary time, the scarp was revealed by a later uplift which etched out the less resistant Triassic sediments. Such a scarp is known as a fault-line rather than a fault scarp since it is the indirect rather than the direct result of faulting. Since it is facing in the same direction as the original fault scarp it is known as a resequent fault-line scarp.

Continue west on U. S. Route 46 on the floor of glacial lake Passaic. Route 46 goes up the escarpment of the Reading Prong (resequent fault-line scarp) at an angle so as to leave a more gentle slope. Note the boulders of the Terminal Moraine of Wisconsin glaciation.

40.0 STOP FIVE: TO OBSERVE GLACIAL BOULDERS OF SKUNNEMUNK CONGLOMERATE.

Turn right (N) and park at real estate office. This is the first turn possible off U. S. Route 46 upon entering the Reading Prong of the New England Province. The glacial boulders are of the Skunnemunk conglomerate. They are composed of milky quartz pebbles in a dark red matrix. These boulders of Devonian age were carried here by Wisconsin glaciation from outcrops in the Hudson Highlands approximately 30 miles to the north.

Continue west on U. S. Route 46. We are in the Precambrian crystalline area of the Reading Prong. High points along the route are Precambrian gneisses with a foliation striking northeast roughly parallel to the general structure of the region.

49.0 STOP SIX: WESTERN EDGE OF MINE HILL OVERLOOKING GERMAN VALLEY.

Note the even skyline of Schooley Mountain just west of German valley. This is the type example of the Schooley peneplane (Tertiary). German Valley is one of many down-faulted valleys in the Reading Prong. It is underlain by the Kittatinny limestone, Cambro-Ordovician in age. At the time of Schooley peneplanation its surface was at the same level as the more resistant Precambrian crystallines. With a later regional uplift the valley was etched out, leaving a resequent fault-line scarp as a western and an exhumed Precambrian peneplane as an eastern border. SEE CHART 2 showing these relationships.

Continue west on U. S. Route 46. The route goes down onto the floor of German Valley, and then up onto Schooley Mountain. After passing Budd Lake we are traversing the rolling upland of Schooley Mountain. The terrain shows an accordance of summits and a moderate relief to be expected in an uplifted Tertiary peneplane where later erosion has taken place. The Schooley peneplane here is about 1100 feet above sea level.

61.5 STOP SEVEN: MUSCONETCONG VALLEY OVERLOOK.

This stop is on the shoulder of U. S. Route 46 when the Musconetcong Valley first comes into view. This valley is a downfaulted syncline of Kittatinny limestone (Cambro-Ordovician) and Martinsburg shale (Ordovician). The valley is graben-like in form and was revealed by post Schooley erosion. Thus the borders again are resequent fault-line scarps. Two levels can be seen in the valley. Some geomorphologists would consider the upper level on the Martinsburg shale to be the Harrisburg partial peneplane and the lower level on the Kittatinny limestone to be the Somerville partial peneplane. We are still in the Reading Prong. SEE CHART 3 showing these relationships.

63.2 Lunch at Hackettstown Diner.

63.4 Turn left (S) from U. S. Route 46 onto N. J. Route 57. The route follows the Musconetcong River which flows on the non resistant Kittatinny limestone (Somerville partial peneplane). The higher level to the west is underlain by the more resistant Martinsburg shale (Harrisburg partial peneplane).

68.9 At this point on N. J. Route 57 we pass outcrops of Martinsburg shale.

74.6 Turn right (N) from N. J. Route 57 in Washington N. J. to N. J. Route 31. Note Many people think that their cars have flat tires at this point. Actually this concrete road has a strong washboard effect.

76.5 STOP EIGHT: VIEW OF SCOTTS MOUNTAIN WIND GAPS

Stop at shoulder of N. J. Route 31. We are now again in one of a series of north east trending valleys eroded on Paleozoic sediments in the Reading Prong. To the west are the resistant Precambrian crystallines of Scotts Mountain. Observe the remarkable series of wind gaps cut in the resistant pre Cambrian metamorphic rocks. Since the axes of the gaps converge to the southeast, it appears that they were formed by tributaries of a southeastward flowing master stream all of which have been superimposed over the area. After a post-Schooley uplift, these streams were beheaded by a headward working subsequent stream flowing in the Pequest Valley to the west of Scotts Mountain leaving the series of wind gaps. The Pequest Valley is another in the series of northeast trending valleys of Paleozoic sediments (Kittatinny limestone) in the Reading Prong. In this case it was an unfaulted syncline dropped below the Schooley baselevel. SEE CHART 4 which shows these relationships.

78.2 View of the Delaware Water Gap 14 miles away on the far side of the Great Valley. N. J. Route 31.

82.6 Turn left (W) onto U. S. Route 46 at its junction with N. J. Route 31.

83.4 We are now in the Great Valley sections of the Folded Appalachian Province. Outcrops of the Cambro-Ordovician Kittatinny limestone on the right. In this part of the Great Valley (here called the Kittatinny valley) the formations are the Kittatinny limestone and the Martinsburg shale, Ordovician. The regional dip is to the West.

Continue along U. S. Route 46 to the flood plain of the Delaware River. Note that the trunks of the trees on the islands are all tilted in a downstream direction, a clear result of the action of floodwaters. Outcrops of the Martinsburg shale on the right.

92.4 Turn right from U. S. Route 46, which has just become U. S. Route 80, to cross toll bridge to Portland, Pennsylvania. Good view of Delaware Water Gap in Kittatinny Mountains to the right. The even skyline of this mountain, at an altitude of about 1600 feet, is considered by some geomorphologists to be the uplifted Schooley peneplane level.

93.0 Turn right having crossed toll bridge and then turn immediately to the left (NW) on U. S. Route 611.

96.3 STOP NINE: ARROW ISLAND OVERLOOK OF DELAWARE WATER GAP.

We have now left the Great Valley Section of the Folded Appalachians and are now in the Ridge and Valley section of the Folded Appalachians. The regional dip is still westerly. Kittatinny ridge is composed of the very resistant Tuscarora (Shawangunk) conglomerate of Silurian age. According to Douglas Johnson there is no indication of major faulting or other structural weakness transverse to the bedding at this point and therefore he interpreted the water gap as resulting from the superposition of a consequent stream flowing southeastward on a Cretaceous Coastal Plain covermass down onto the underlying Tuscarora conglomerate. Arthur Strahler supported Johnson's interpretation stressing that there is a lack of coincidence between the various gaps and sites of structural weakness.

On the other hand, Jack B. Epstein interpreted the wind and water gaps including the Delaware Water Gap as resulting from structural control rather than from regional superposition. He pointed out that the dip on the New Jersey side of the Delaware Water Gap is about 50° whereas the dip on the Pennsylvania side is less than 25°. From this he came to the conclusion that there must be extensive fracturing of the rocks. He implied that a pirate stream worked headward over the Kittatinny ridge and captured the upper Delaware. George W. Stose believed that an east flowing river flowed on a peneplane covered by a thick blanket of alluvium. With uplift during Cretaceous and Tertiary time the river cut down into the Tuscarora conglomerate and formed the Delaware Water Gap. This is a modification of Douglas Johnson's interpretation.

Continue on U. S. Route 611 through the Delaware Water Gap. Dipping to the west and overlying the Silurian Tuscarora conglomerate is the Silurian Bloomsburg (Clinton) red beds. It is also a resistant formation in this locality. With the west dip continuing we next come to the Silervian High Falls sandstone with red and grey beds. Looking to the right across the Delaware river on the New Jersey side we see the faulted Kemmerville anticline.

99.4 U. S. Route 611 makes a sharp left turn (SW) as it starts to ascend the anticlinal Godfrey ridge.

101.1 STOP TEN (OPTIONAL): TO COLLECT DEVONIAN FOSSILS ON GODFREY RIDGE.

The stop may be made at a restaurant parking lot at the top of Godfrey ridge. Walking down the road one comes sucessively to outcrops of Esopus sandy shale, Oriskany sandstone and finally Helderberg limestone.

101.3 Looking about eight miles to the west we see the next geomorphic province, the Appalachian plateau here called the Poconos. It is underlain by the resistant gray Pocono sandstone in practically horizontal attitude.

101.8 Right turn from U. S. Route 611 toward U. S. 80 West.

102.3 Enter U. S. Route 80 West.

104.1 Leave U. S. Route 80 for U. S. 209 South (not business 209).

110.9 U. S. Route 209 joins Pennsylvania Route 115 South.

113.7 Turn right (W) from Pennsylvania Route 115 at Saylosburg exit. Drive-in Movie Screen near exit. Turn left (S) on old road to Wind Gap.

115.7 STOP ELEVEN: VIEW OF WIND GAP.

This is the type example of a geomorphic feature found in many parts of the world. The bottom of the gap is 981 feet in altitude with the top approximately 500 feet higher. A study of this and other wind and water gaps of the Appalachians convinced Karl Ver Steeg and Douglas Johnson that eastward flowing consequent streams were superimposed through Cretaceous convermass deposits onto the ridges forming the various wind and water gaps of the Folded Applachians. Discussion of these ideas with several diagrams.

117.6 After driving through Wind Gap, turn left (NE) on county road 512 toward Pen Argyl.

123.0 Turn right in center of Bangor and then first left on continuation of county road 512.

124.1 STOP TWELVE: QUARRY OF CAPITOL SLATE COMPANY.

This is one of the quarries in the Martinsburg slate, Ordovician. It is a leading producing area of slate in the United States. Note the large piles of discarded slate. The slate was discarded largely because of prominent original bedding (ribbon) seen on the surface of the slaty cleavage. Continue NE on county road 512.

128.7 Turn left (NE) onto U. S. Route 611 toward Portland Pennsylvania.

131.0 Turn right (SE) onto U. S. Route 46 having crossed the toll bridge into New Jersey.

160.5 Turn right (E) from U. S. Route 46 onto U. S. Route 80 in Netcong.

197.4 We are now back in Rutherford having left U. S. 46 again to join New Jersey Route 3.

(References - Next Page)

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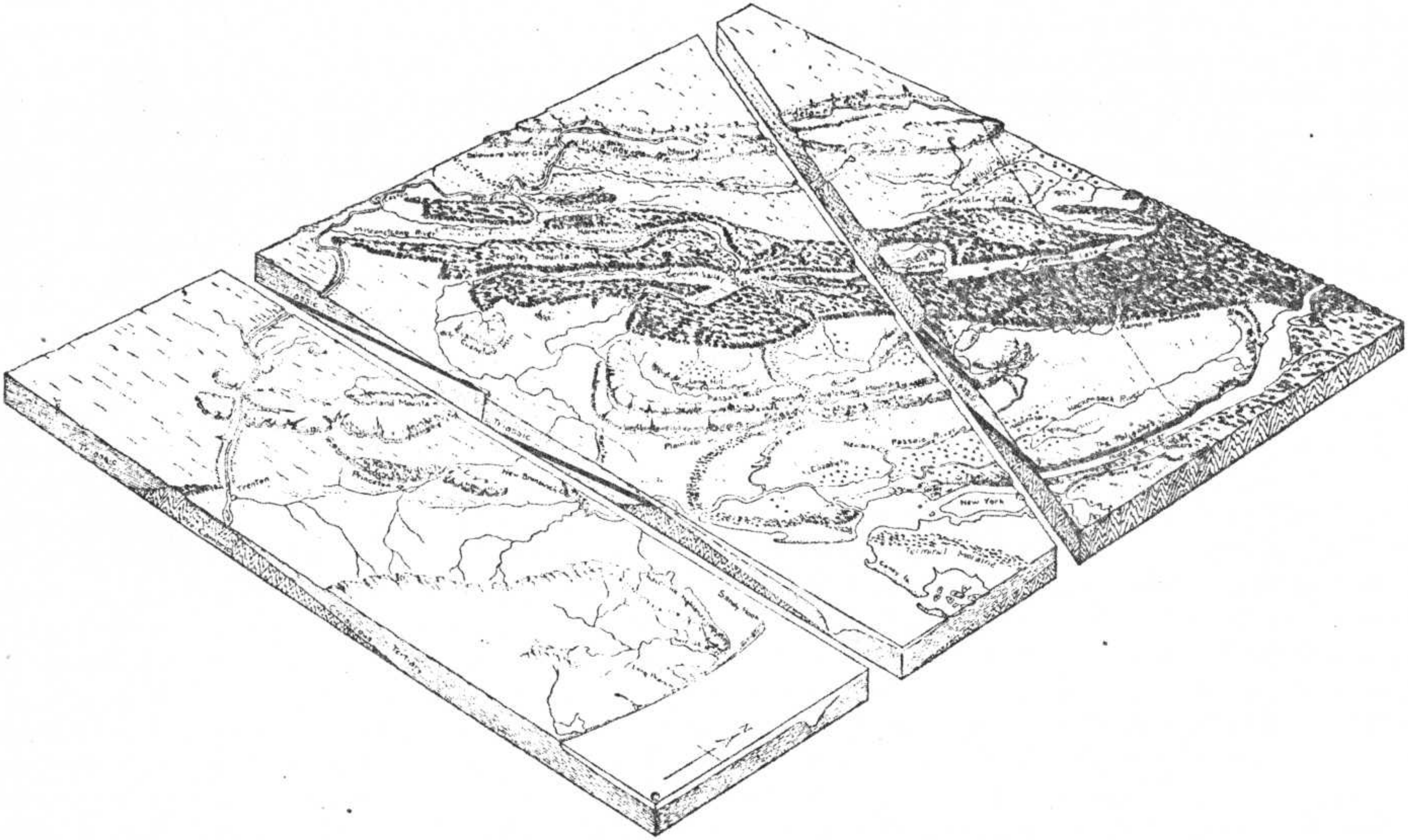


A. BLOCK DIAGRAM OF NORTHERN NEW JERSEY, showing structure of the TRIASSIC LOWLAND. (N.Y. Acad. Sciences)

1. Prepare a LEGEND for this map to show sequence of formation represented in this region.

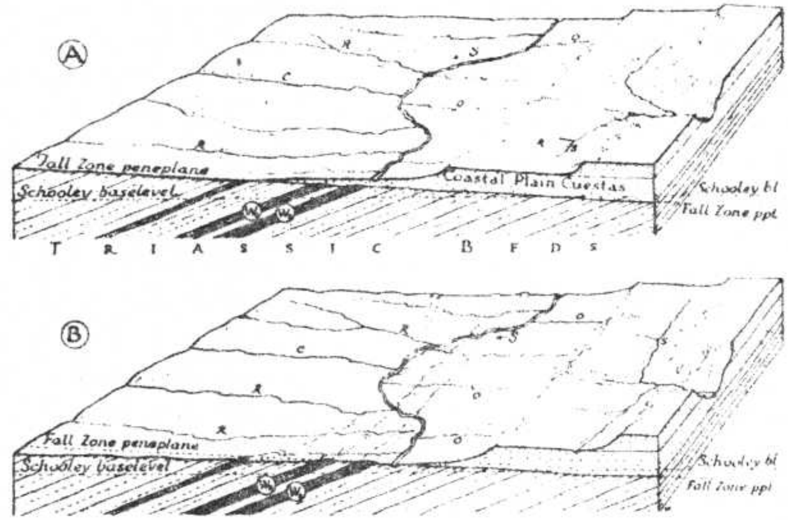
2. Color the geological sections appropriately, and add one more section to show structure along the north end of the block. Label all the physiographic provinces included in this area. Label also the Reading and Manhattan Prongs of New England, and the Cuesta of the New Jersey Coastal Plain.

3. What structural feature determines the western side of the Triassic Lowland? What determines the position of the Hudson River? Why, do you suppose, the Hudson River is so wide at Haverstraw?

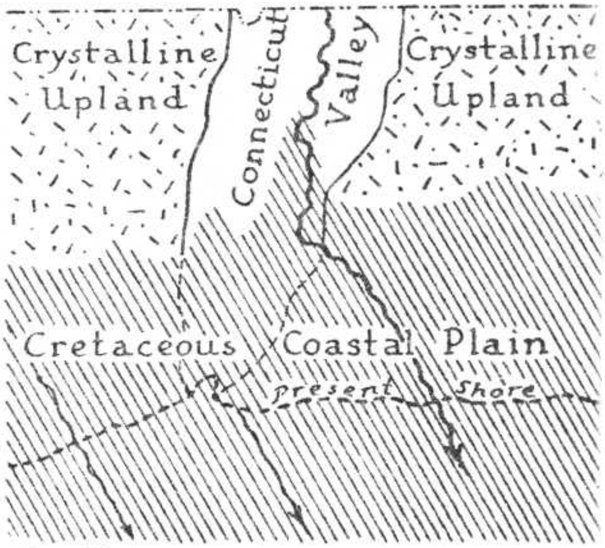
4. Explain the curving ends of the Watchung Ridges. Explain the shape of Cushetunk Mountain.

5. Note the big loops in the form of the Terminal Moraine. Why is this? Do you see any relation between the position of Lake Hopatcong and the Terminal Moraine? Label the "Narrows" at the [illegible]

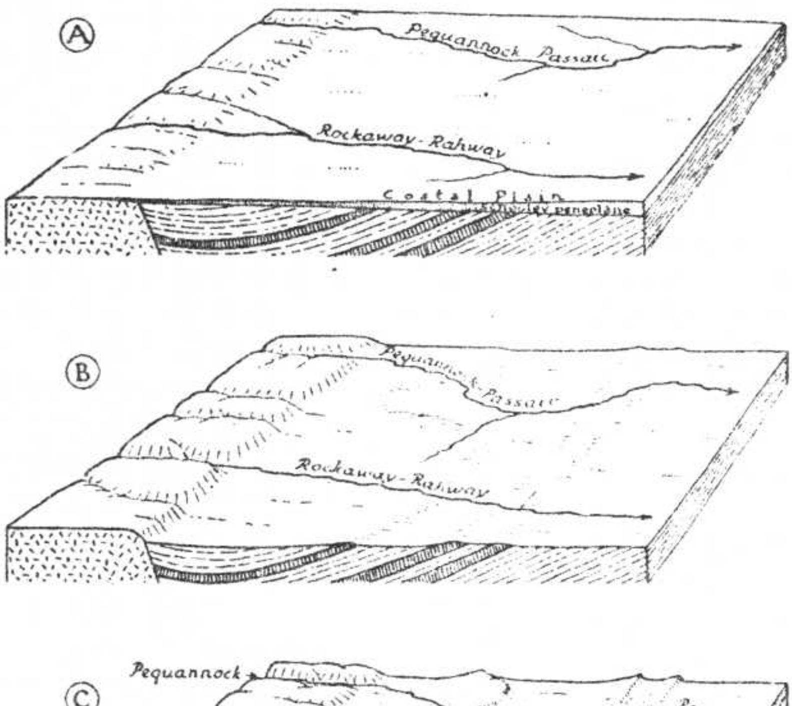
THE TRIASSIC LOWLAND



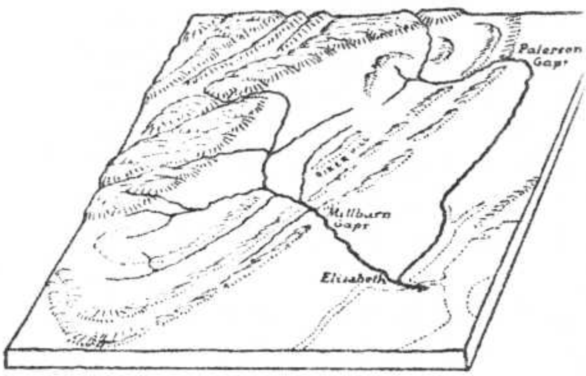
A. EXPLANATION OFFERED BY Prof. Johnson for the GAPS IN THE WATCHUNG RIDGES AT PATERSON AND MILLBURN. (Johnson: Atlantic Slope. Col. Univ. Pr.)
1. Label the two sets of gaps. (Paterson is at S.)
2. The letters stand for Consequent, Subsequent, Resequent and Obsequent.
3. If this explanation is correct which of these gaps would be deepest and which the shallowest?



B. FORMER EXTENT OF THE COASTA PLAIN IN CONNECTICUT. (Johnso
1. What type of stream is the lower Connecticut? Is there any evidence that the coastal plain ever extende this far inland? How does this expla the Connecticut gorge? Label the gorge



C. EXPLANATION OFFERED BY Profess Davis for the GAPS IN THE WATCHU RIDGES. (From Johnson: Atlantic Slope,
1. In what respect are Johnson's and Davis explanations alike and in what respect different?
2. If Davis is correct what would b true about the relative depths of the different gaps? Why is it so difficu to determine which one of these explanations is correct?



D. MAP TO ILLUSTRATE THE THEOR ADVANCED BY Professor Salisbury
1. Salisbury thought the Pre-glacial rivers were as shown above. If so, ho did the ice sheet change the drainag Where, for instance, is the Terminal Moraine?

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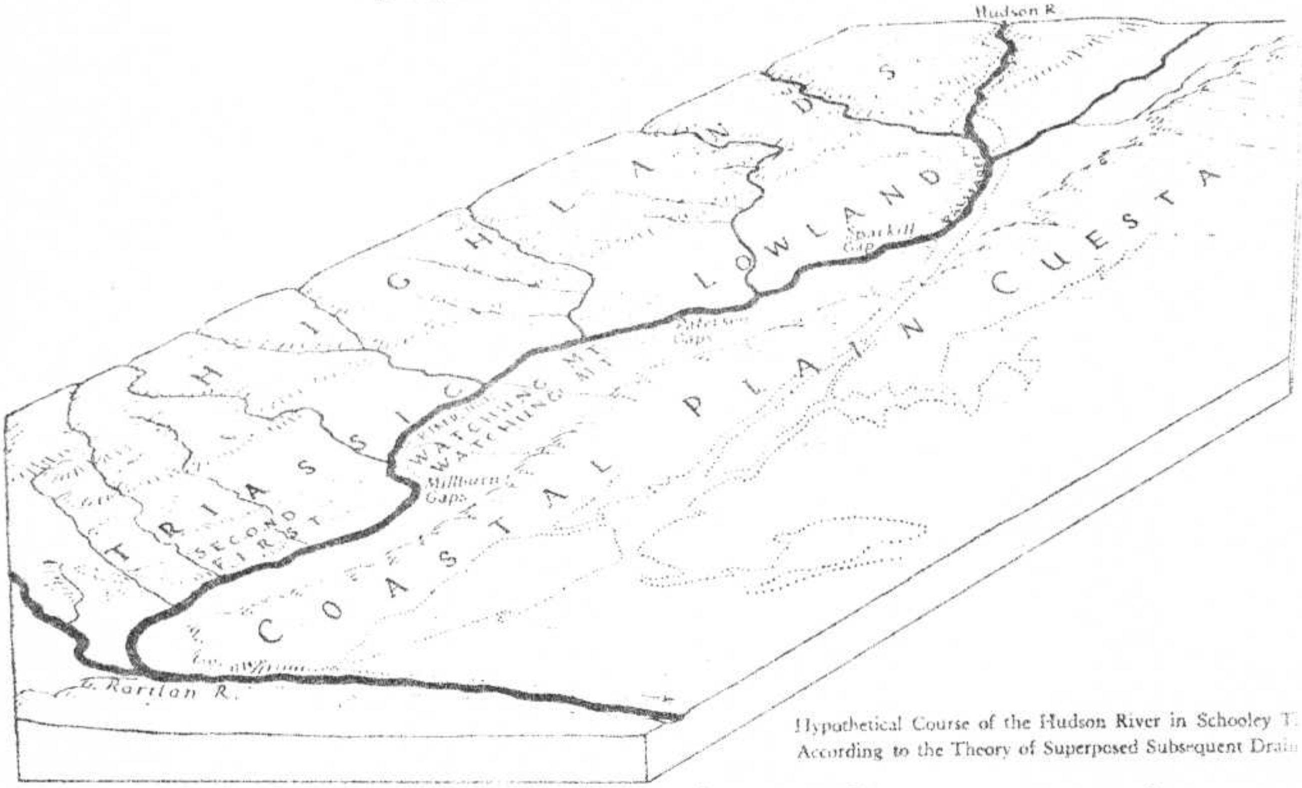
THE TRIASSIC LOWLAND

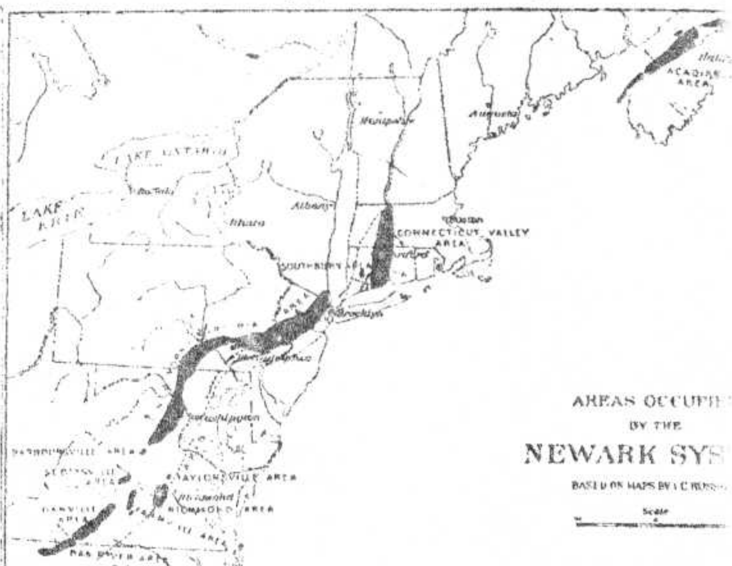


A. DIAGRAM TO ILLUSTRATE Professor Johnson's THEORY FOR THE ORIGIN OF THE GAPS IN THE WATCHUNG RIDGES. (Drawn by E. J. Raisz for Johnson: Atl. Sl

1. Where is the Coastal Plain Cuesta at the present time?
2. Is the Triassic Lowland the same as the Inner Lowland? Explain.
3. Does this theory also explain the Hudson River Gorge through the Highlan
4. What should be the relative depths of the different gaps if this theory is correct

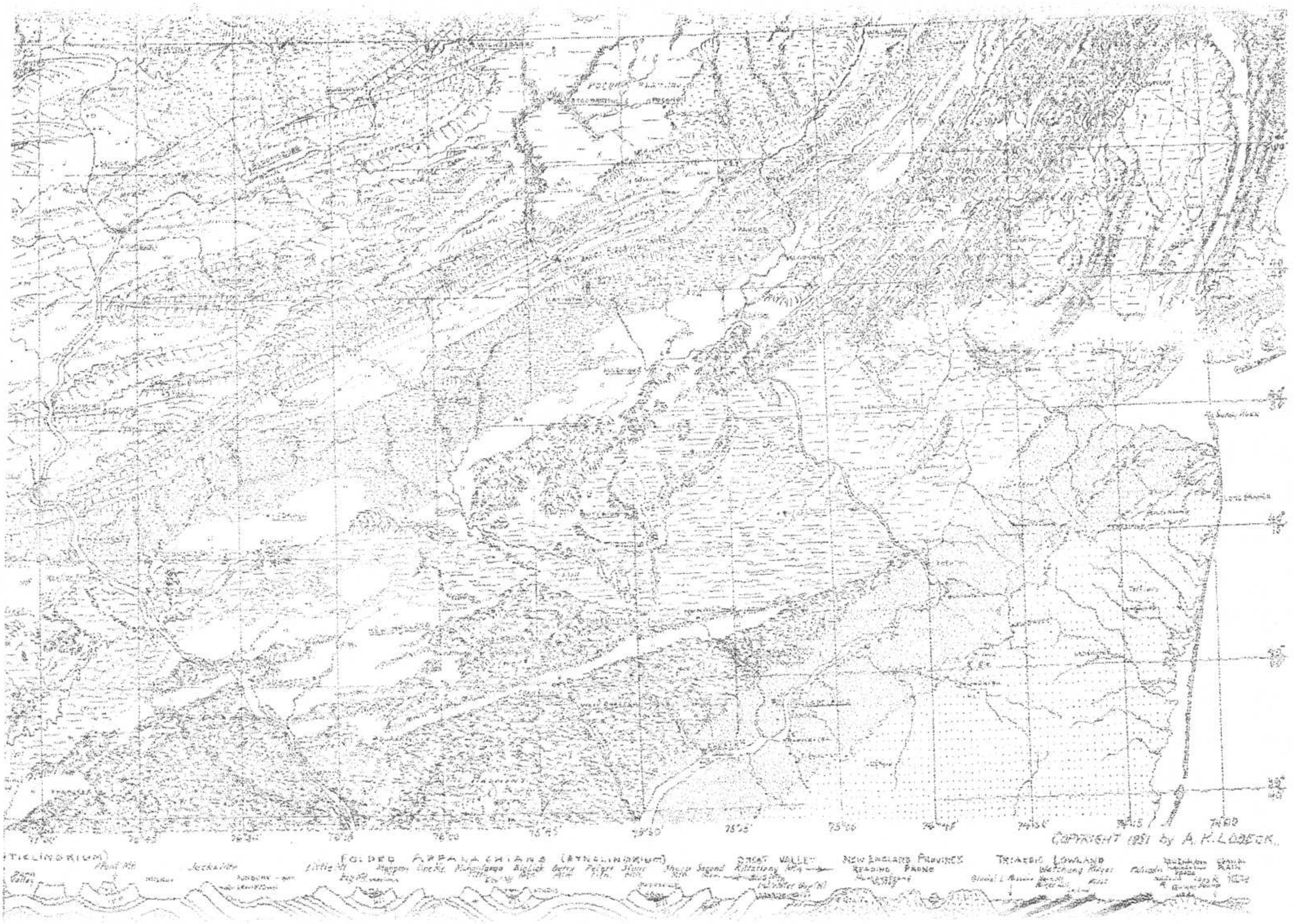
B. LAKE PASSAIC (U.S.G.S. Folio 157)

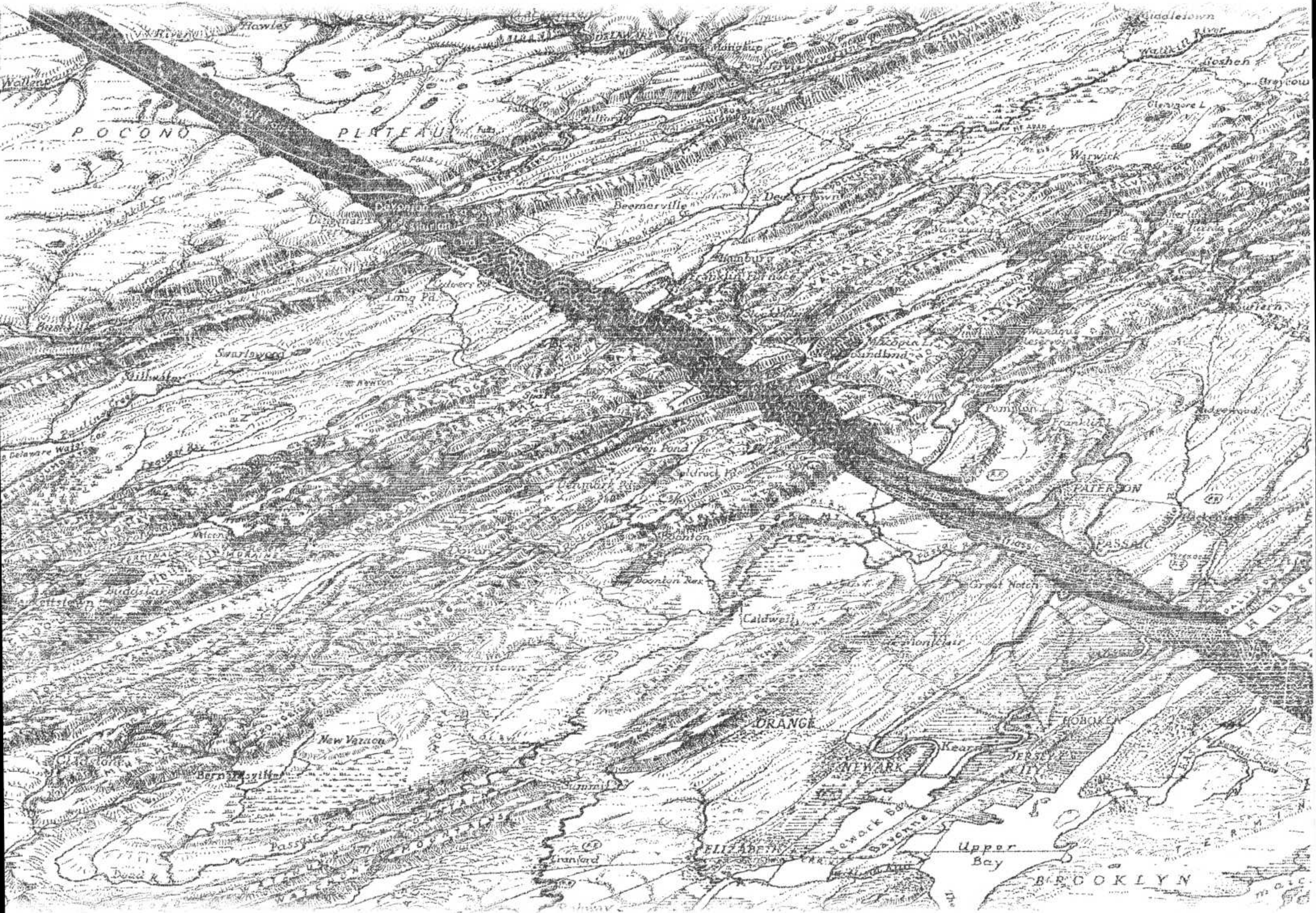
1. What caused Lake Passaic and why does it no longer exist?
2. Where was its outlet during its maximum stage? Why not through the gap at Short Hills?



C. THE TRIASSIC AREAS OF THE EASTERN U.
(From Hobbs: Newark System, Bull. G.S.A.

1. Do the Triassic rocks everywhere dip in th same direction? What is a possible explana for this? Which one of these areas is know the Triassic Lowland?


FOLDED APPALACHIANS (SYNCLINORIUM)
GREAT VALLEY
NEW ENGLAND PROVINCE
READING PRONG
TRIASSIC LOWLAND
Watchung Ridges



Hawley
Wallenpaupack
POCONO
PLATEAU
Middletown
Wallkill River
Goshen
Warwick
Beemerville
Devonian
Silurian
Long Pd.
Hamburg
Swartswood
Stillwater
Pompton
PATERSON
PASSAIC
Boonton Res.
Great Notch
Caldwell
Montclair
ORANGE
NEWARK
Kearny
JERSEY CITY
New Vernon
ELIZABETH
Cranford
Newark Bay
Upper Bay
BROOKLYN

Atlas of American Geology

THE FOLDED APPALACHIANS

1

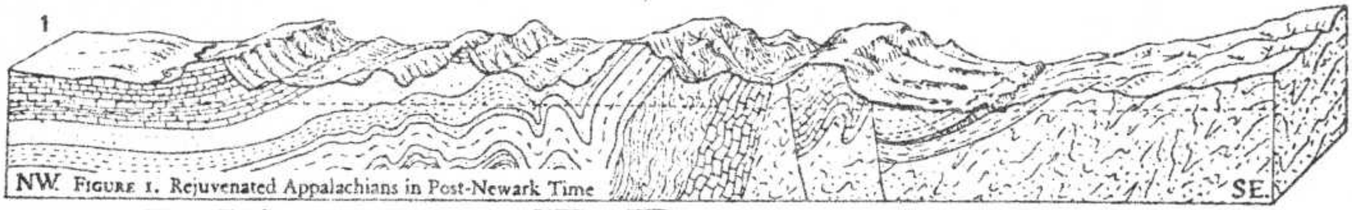


FIGURE 1. Rejuvenated Appalachians in Post-Newark Time

2

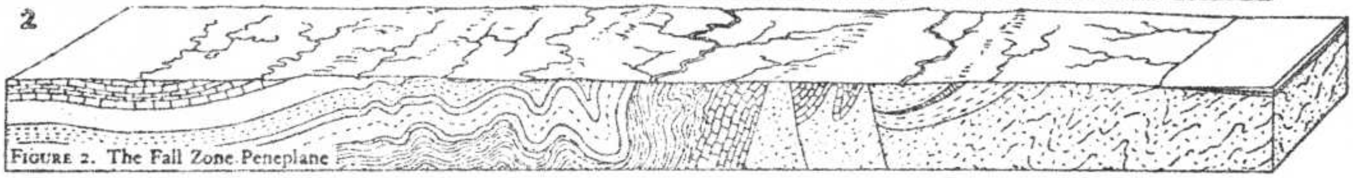


FIGURE 2. The Fall Zone Peneplane

3

FIGURE 3. Encroachment of Cretaceous Sea and Deposition of Coastal Plain Beds

4

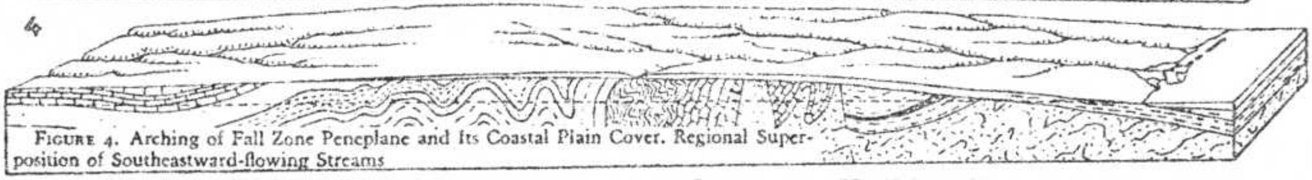


FIGURE 4. Arching of Fall Zone Peneplane and Its Coastal Plain Cover. Regional Superposition of Southeastward-flowing Streams

5

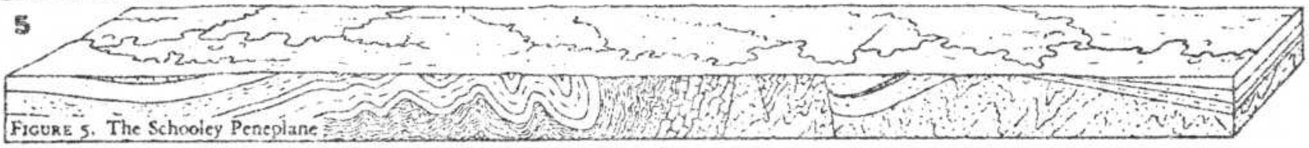


FIGURE 5. The Schooley Peneplane

6

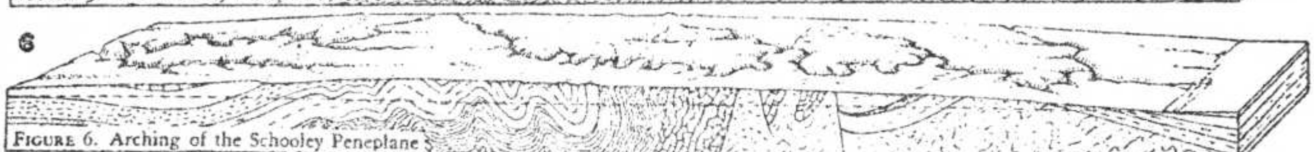


FIGURE 6. Arching of the Schooley Peneplane

7

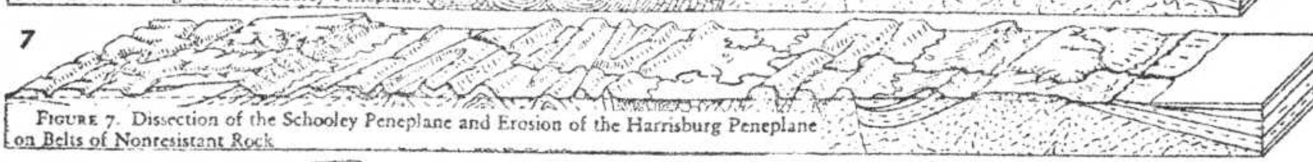


FIGURE 7. Dissection of the Schooley Peneplane and Erosion of the Harrisburg Peneplane on Belts of Nonresistant Rock

8

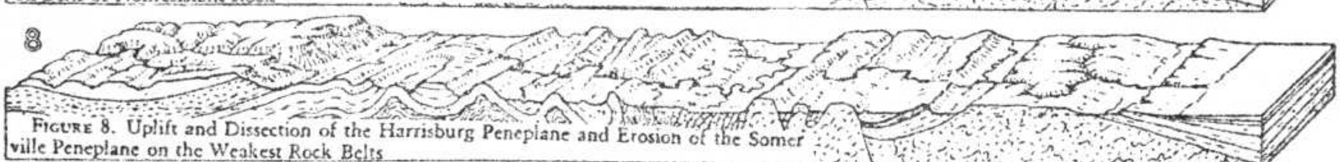


FIGURE 8. Uplift and Dissection of the Harrisburg Peneplane and Erosion of the Somerville Peneplane on the Weakest Rock Belts

9

FIGURE 9. Uplift and Dissection of the Somerville Peneplane to Give Present Conditions

Allegheny Front | Ridge and Valley Belt | Great Valley | Reading Prong | Trias lowld | Piedmont | Fall Zone
APPALACHIAN PLATEAU | NEWER APPALACHIANS | OLDER APPALACHIANS | COASTAL PLAIN

Drawn by E. RAISZ

A. STAGES IN THE DEVELOPMENT OF THE APPALACHIAN REGION. (Johnson)

1. Study this series of drawings and then on the last one color on the surface the remnants of the different peneplanes in order to distinguish them.

2. Color the section and surface of Fig. 8 to show geological formations, and append a legend which should include: a, Pre-Cambrian Crystallines; b, Cambro-Ord. Limestones; c, Ord. shales; d, Silurian Sandstone; e, Devonian Shales and Sandstones; f, Carboniferous Sandstones; g, Triassic Sandstone and Trap; h, Cretaceous Clays, marls, and sands.

SEDIMENTOLOGY AND GENERAL STRUCTURE OF THE NORTHERN PORTION OF THE NEWARK BASIN

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Introduction

The Upper Triassic strata of the New York-New Jersey part of the Newark basin constitute the uneroded remnant of a formerly more extensive deposit. Just how much more extensive than the present outcrop belt is not positively known and has been, even still is, hotly debated. The purpose of the present trip is to examine a few selected exposures that illustrate the stratigraphic relationships, the sedimentological characteristics of the strata, and the geologic structure. I hope that you will find the trip in itself instructive and enjoyable quite apart from any beliefs you hold concerning the question of the former extent of the strata. If a definitive solution to this disputed subject is ever found, I suspect that it will not be the result of simple examination of the strata in the field, as we shall do on this trip. If that was all one needs to do to find the answer, the questions should have been solved a long time ago. After all, some very astute and intelligent geologists have looked at these strata and have not agreed on this point of interpretation.

Along their northeastern and southeastern boundaries the inclined Triassic strata of the Newark basin are truncated along their updip edges by the modern land surface. On their northwestern side the Triassic strata of this basin abut the Ramapo fault (the fascinating subject of one of the companion trips). Because this fault was active during Triassic sedimentation (as one of its many episodes of movement which span a remarkably long period of time), it is virtually certain that the Triassic strata never extended toward the northwest much beyond this fault, or if they did so, they overlapped it only locally and for comparatively short distances. With this generalized sketch of the Newark basin, let us now take up the debate about the former extent of the strata.

Concerning the former extent of the Triassic strata, not only of the Newark basin, but of the other basins as well, two schools of thought have grown up: (1) the "isolated-basin" school and (2) the "broad-terrane" school. The following remarks summarize the positions held by these two schools of thought and some of the arguments used in support of each.

According to the "isolated-basin" school the Triassic strata never extended through much more extensive areas than their present belts of outcrop. In general, advocates of the "isolated-basin" school prefer small values for the thickness of the Triassic strata and tend to consider that post-Triassic deformation and erosion have been relatively inconsequential. In fact, one of the early proponents of this school of thought, W. B. Rogers (1839, 1840, and elsewhere), even went so far as to deny that the inclined Triassic strata had ever been horizontal (hence that the present dips signify anything in the way of geologic structure). Rogers thought that the inclination of the Triassic strata resulted from conditions of sedimentation. In modern terms we would say that he considered the dipping strata to be gigantic cross-beds. He inferred that these strata had been formed in a great estuary by currents which built a long delta-like embankment of sediment from the southeast toward the northwest.

More recent arguments which have been cited in favor of the "isolated-basin" point of view include evidence that some Triassic sediments were supplied from the updip sides of the Newark outcrop belt (for example, Glaeser, 1966; Savage, 1968; and Klein, 1969), and K-Ar dates on detrital minerals in the sandstones of the Newark Group which indicate that the particles were derived from a metamorphic terrane whose last recrystallization occurred about 350million years (MY) ago (Abdel-Monem and Kulp, 1968). Because metamorphic rocks which last recrystallized 350MY ago (New York City Group) are exposed in Westchester County, New York, just across the Hudson River from the basal Triassic strata of the Newark Group, the point has been argued that the Westchester rocks served as a source of the Triassic sediment supplied to Rockland County, New York, from what is now the updip direction. If much Triassic sediment were indeed derived from Westchester County, then it is obvious that the Triassic strata never extended far enough eastward to have covered these presumed source rocks. Manifestly the same rocks cannot at the same time be both the floor on which the Triassic strata were deposited and the uplifted blocks which supplied sedimentary debris to form the Triassic strata. The rebuttal to this line of argument is found in a later paragraph, which deals with the "broad-terrane" interpretation, to which I now turn.

According to the "broad-terrane" school (proposed by I. C. Russell, 1878, 1880; and including Girard Wheeler, 1937, 1938; and me as staunch members), on their updip sides the Triassic outcrop belts formerly extended considerable distances away from their present truncations. The modern version of the "broad-terrane" interpretation includes the concept that some or all of the now-separated outcrop belts formerly were connected and that the Triassic strata were deposited not in isolated basins but in one or more great graben. The present outcrop belts are inferred to be erosional remnants of the strata deposited near the sides of this graben. Members of the "broad-terrane" school perfer large thickness values for the Triassic strata and, of necessity, must argue that post-Triassic deformation and erosion have been considerable. In the "broad-terrane" view, the strata originally deposited in the center of the graben have been uplifted and eroded; indeed, the pre-Triassic rocks between paired outcrop belts having opposing dip directions are considered to be the rocks of the graben floor, which have been re-exhumed and re-exposed at the Earth's surface as a result of great post-Triassic uplift and deep erosion.

My rebuttal to the "isolated-basin" school's arguments based on derivation of sediment from the updip sides of the Newark outcrop belt and on the 350MY-age of the detritus is to say: "This is all very well, good, and true, but so what?" I do not find anything at all conclusive about finding 350-MY-old sediment derived from the southeast. What is there about this information that tells how far from the southeast? Does the finding of 350-MY-old rock in Westchester County, New York prove that this was indeed the source? Does it rule out all other possible sources? According to me it definitely does not. In my version of the "broad-terrane" interpretation I can easily derive this 350-MY-old sediment from the southeast by having it come from the bedrock forming the southeast wall of the graben. Such sediment could easily have traveled northwestward beyond the center of the graben to its present locations. Such sediments derived from the southeast wall of the graben would have been deposited by streams that flowed northwestward (as the cross-strata in the Stockton Formation indicate), would consist of feldspar (as they do), and could easily have been eroded from source rocks which last recrystallized 350MY ago (rocks of this isotopic age are known just east of the Triassic border fault in southern Connecticut and may well extend southward under eastern Long Island). Until detailed provenance studies are carried out on the crystal morphology and other details of the particles in the Triassic sediments derived from the updip sides of the outcrop belts, we will not know anything conclusive about the merits of the "isolated-basin" vs. the "broad-terrane" school. based on arguments involving direction, general composition, or age of sediment.

From Stony Point, New York, to the Lincoln Tunnel near Hoboken, New Jersey, the Hudson River follows the curving strike valley that has been sculpted along the contact at the base of the Triassic strata. What seems to me to be a singularly unappreciated fact is that the curvature of this dipping basal contact surface (as indicated by the path of the Hudson River) is resolutely congruent with the curvature of the high Newark beds (as indicated by the outcrop belt of the Second Watchung extrusive sheet within the Brunswick Formation, for example). I take this congruence of curvature to mean that two surfaces, originally essentially planes, parallel to each other, and formerly horizontal, subsequently have been deformed together as parts of the same major geologic structural features.

I think that this point is self-evident to anyone accustomed to visualizing the three-dimensional significance of strikes and dips and outcrop patterns. But, because this point has been so consistently overlooked, I offer the following explanation in basic English (Run, Dick, run; dip, strata, dip). A convenient way to visualize the map pattern of the Newark strata in the northern end of the Newark basin is to think of a capital letter D. A slight modification is necessary; the curved part cuts off against the vertical straight part and does not extend beyond it, as does the curving part of the capital D on this typewriter. Now, compare the straight part of the D with the straight course of the Ramapo fault. Compare the curved part of the D with the outcrop trace of the unconformable surface at the base of the Triassic succession or with the outcrop trace of the Triassic strata. Choose any strata from the base up to some part of the Brunswick Formation that overlies the Second Watchung extrusive sheet and underlies the Third Watchung extrusive sheet. The Third Watchung sheet is folded on smaller structures than is the Second sheet, as we shall see in the field.

This curvature of formerly horizontal and plane surfaces can be explained in several ways. We shall start with the explanation I prefer, namely the one that involves the intersection of three anticlines, all three of which involve not only the Triassic strata but the pre-Triassic basement rocks as well.

The first of these three anticlines is a regional arch trending NE-SW, parallel to the Ramapo fault. This arch has been named the "Taconic geanticline" (Barrell, 1915), but that term has not been widely adopted. Despite its lack of acceptance, I shall continue to employ it in this discussion, but without intending any stamp of approval. To show my neutrality on this point I shall retain the quotation marks. The axis of this "Taconic geanticline" lies somewhere southeast of the Hudson River and west of Southbury, Connecticut (where in a small preserved remnant the Triassic strata dip eastward). Along the northwest flank of the "Taconic geanticline" the Triassic strata of the Newark basin strike N20°E and dip 15°NW. This major regional arch, then, is responsible for the regional dip of the Newark strata.

The second of the three anticlines trends NW-SE, at a right angle to the Ramapo fault. The axis of this anticline lies somewhere northeast of Stony Point, New York and southwest of New Haven, Connecticut. Because the axis of this fold is inferred to pass through Danbury, Connecticut, I have namedit the Danbury anticline (Sanders, 1960). Along the southwest limb of the Danbury anticline the Triassic strata of the Newark basin strike about N 45°W and dip 10 to 15°SW.

Not all geologists who have studied the northern end of the Triassic basin have recognized this anticline. In fact, McLaughlin (1957, p. 1497-1498) has expressed what is a widely adopted view that the Newark basin is "shelving" to the northeast. The only reason I can fathom for this concept is that those who hold it fail to recognize that the strike of the Triassic strata changes from NE-SW to NW-SE. At Stony Point, we shall see for ourselves on this point.

According to my minority analysis, the Danbury anticline is a structure that ends on the northwest against the Ramapo fault. In fact, I visualize this fault as being a necessary part of the origin of the anticline. Along the fault the Triassic strata were free to fold independently of the basement rocks lying to the northwest. As I see it, the Newark basin outcrop belt stops at the northeast end because the pre-Triassic floor has been elevated to the level of the present land surface in the axial part of the Danbury anticline. This concept implies that the upward movement along the axis of this anticline, after deposition of the entire succession of Triassic strata in an essentially horizontal position, has exceeded the total amount of downdropping of the pre-Triassic peneplane (Sharp, 1929) along the Ramapo fault during Triassic deposition. The preserved thickness of the Newark strata in northern New Jersey and in Rockland County, New York is not exactly known. I favor the view that this thickness is approximately 25,000 feet. Whether or not this is correct, I estimate that the amount of uplift in the axial parts of both the "Taconic geanticline" and the Danbury anticline exceeds the thickness of the Triassic strata by about 5,000 feet. If 25,000 is the correct thickness of the Triassic strata, then the uplift on these two anticlines must have been at least 30,000 feet.

Where the axis of the Danbury anticline abuts the Ramapo fault the net effect of the inferred upward movement in excess of the original thickness of the Newark strata has been to create what today looks like a scissors fault, with the fulcrum lying near Stony Point, New York. Along the axial part of the Danbury anticline the net movement along the Ramapo fault is such that the <u>southeastern</u> side is now relatively <u>upthrown</u> with respect to the northwestern side. <u>Surely during</u> late Triassic <u>time throughout</u> its extent the relative movement along the Ramapo fault was relatively <u>downthrown</u> on the southeast side. The inferred subsequent net reversal of <u>throw along</u> the Ramapo fault is ascribed to the great postdepositional uplift along the axis of the Danbury anticline.

The third of the three anticlines likewise trends NW-SE. This third anticline lies southwest of Bound Brook, New Jersey. It is much less obvious than the other two anticlines; it has been displaced by faults and has been covered in part by the overlapping Cretaceous strata of the coastal plain. I have named this third anticline the Somerville anticline (Sanders, 1962).

The present discussion emphasizing the anticlines contrasts sharply with those published by previous workers, who have tended to ignore the anticlines and instead to write about the synclines or "half basins" outlined by the curved edges of the strata (for example, Girard Wheeler, 1939).

It is my opinion that the folds affecting the Triassic strata have been ignored because geologists concerned with the Newark rocks have been hypnotized by the notion that the Triassic strata indicate the effects of crustal tension. This idea permeates all textbooks of historical geology; and as Adolph Knopf used to remark, the material in the first course the students drink in "like they did their mother's milk." I think geologists have quaffed overdoses of this elixir of "tension." As long as the Triassic strata were considered to have resulted from incidental crustal tension accompanying the final dying-out phase of the Appalachian orogeny, there simply was no place for any folds, features which imply crustal compression. This "tension" brew has proved to be heady stuff and not easily eliminated. It persists even in the midst of the flowering of our new concepts of global tectonics (for example, Bird and Dewey, 1970). This is unfortunate, for properly understood, I think the ideas of global tectonics at last afford us a framework of reference large enough for explaining the Triassic rocks of eastern North America (Sanders, 1971).

The trip follows a circular route in a counterclockwise direction. This plan has been adopted to enable us to be examining the sandstones on the west bank of the Hudson River between Rockland Lake Landing and Upper Nyack in the morning light. We will examine the Triassic strata in a few locations where the attitudes of the strata define the limbs of the "Taconic geanticline" and the Danbury anticline. In addition we will examine folds on a smaller scale that have affected the Third Watchung extrusive sheet in the vicinity of Mountain View, New Jersey.

The route lies within the following 7 1/2-minute topographic quadrangle maps:

Weehawken (NJ-NY)
Central Park (NY-NJ)
Yonkers (NJ-NY)
Nyack (NY-NY)
Haverstraw (NY)
Thiells (NY)
Sloatsburg (NY-NJ)
Ramsey (NJ-NY)
Wanaque (NJ)
Pompton Plains (NJ)
Caldwell (NJ)
Patterson (NJ)
Orange (NJ)

The 1/250,000 sheets covering the trip area are:

Scranton
Hartford
New York
Newark

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ROAD LOG

This road log is for a trip including 9 stops in the following order:

1.	Triassic sandstone	Rockland Lake Landing, Palisades Interstate Park
2.	Triassic siltstone	Stony Point, town park, near base of Triassic
3.	Paleozoic dolomitic marble	Stony Point area
4.	Triassic conglomerate	Route 9W, just north of Stony Point
5.	Triassic conglomerate	Wesley Chapel, U. S. 202
6.	Precambrian gneiss	Antrim (Suffern), U. S. 202
7.	Triassic conglomerate	Pompton, N. J.; Grand Union parking lot
8.	Third Watchung extrusive sheet and underlying Brunswick beds	Quarry, Beaufort, N. J.
9.	First Watchung extrusive sheet and underlying Brunswick beds	Passaic Falls, on Passaic River, Paterson, N. J.

Most of the log has been compiled from a trip around the circuit in the reverse direction from that to be followed here. Hence, there may be a few places where I have got the directions turned around. I hope no such errors have crept in, but this possibility should be anticipated. The part of the trip from Mountain View to Beaufort and from Beaufort to Paterson has been taken from the topographic maps. I have not made extensive comments about the individual exposures; that is your input into the trip.

Net distance (mi.)	Cumulative distance (mi.)	Directions and remarks
		Starting point is Fairleigh Dickinson campus, Rutherford, N. J., west-central part of Weehawken quadrangle.
0.0	0.0	Turn R into W. Passaic Ave.; proceed W, downslope to Passaic River
0.4	0.4	Stop street; turn L onto Jackson Ave. (County Rte.507); Floodplain of Passaic R.; on L is low strike ridge underlain by sandstones in Brunswick Fm.
0.2	0.6	Jackson Ave. becomes Riverside
0.6	1.2	Jct. N. J. Route 3; take ramp for eastbound lane. Cuts on S side display alternating red sandstones and siltstones of Brunswick Fm., dipping NW on limb of "Taconic geanticline."
0.5	1.7	Junction N. J. Route 17
0.4	2.1	Curve to L, following N. J. 17 northward
1.1	3.2	Underpass for N. J. Route 14; Brunswick Fm. on L side.
2.4	5.6	Proceed under U. S. Route 46 overpass
0.3	5.9	Turn R onto I80, toward G. Washington Bridge.
4.7	10.6	Deep cuts on both sides of I80 display black Lockatong Fm. argillite (near NE limit of this unit). Contact effects of top of Palisades sill have bleached the argillite to gray color and have recrystallized the minerals to a hornfels (Englewood Country Club).

0.8	11.4	Exit to U. S. 9W, northbound
0.2	11.6	Turn L on Fletcher Ave. (U. S. 9W)
2.[illegible]	13.6	Enter Yonkers quadrangle
10	23.6	All along here are cuts showing Palisades Dolerite of the sill; look for glaciated pavements and glacial striations. Ice here flowed from about N20°W to S20°E (<u>not</u> from due N to due S). The striations make about an angle of 40° with the road.
0.1	23.7	After crossing under Palisades Interstate Parkway, look to L for example of a preserved area of deep chemical weathering of dolerate that took place in pre-Wisconsin time. Spheroidal joints are well developed.
0.1	23.8	Enter Nyack quadrangle
0.1	23.9	New Jersey-New York State line (Entrance to Lamont-Doherty Geological Observatory, Columbia University, on R)
0.95	24.85	Traffic light, Palisades (Oak Tree Rd.); continue on 9W
1.25	26.1	Road to Piermont
0.35	26.45	Start bridge across Sparkill Creek. This creek now flows N through Sparkill Gap to join the Hudson R. at Piermont. Formerly the Hudson itself flowed SW through this gap. It followed the low area now occupied by the Oradell Reservoir, Hackensack River, and emptied into the Atlantic Ocean via Newark Bay and Arthur Kill.
0.2	26.65	End bridge over Sparkill Creek.
0.1	26.75	Traffic light, road to Sparkill
0.1	26.85	Traffic light on curve; Rte. 340, Orangeburg Road
3.35	30.2	Rte. 9W splits, bear R
0.1	30.3	Cross over New York Thruway
0.35	30.65	Re-cross N. Y. Thruway; turn R where Rte. 9 comes together again
0.85	31.5	Re-cross N. Y. Thruway
0.1	31.6	Junction N. Y. Rte. 59
0.1	31.7	Intersection High Avenue
0.6	32.3	Enter Upper Nyack
0.6	32.9	Traffic signal; Christian Herald Rd.
0.5	33.4	Hook Mountain; dolerite in cuts on both sides of Rte. 9W
0.5	33.9	(Enter Haverstraw quadrangle)
0.4	34.3	Turn R, entering Palisades Interstate Park opposite Lake Rd. at S end of Rockland Lake. (REST STOP)
1.1	35.4	Bear R on road to Rockland Lake Landing
.5	35.9	Ranger's House, Rockland Lake Landing. STOP 1. Walk down road toward Hudson River. Red sandstones and siltstones near base of Triassic. The naming of these units is not a simple matter. As far as stratigraphic level is concerned they lie where the Stockton Arkose usually occurs. But, these strata are not typical Stockton in appearance. The Stockton usually is not red, is full of feldspar, and displays cross-strata indicating current flow from E to W. These sandstones show the E-to-W flow direction, but no other "typical" Stockton properties. Call them what you will; admire them for their displays of channels and cross-strata. The contact with the dolerite at the S end of the exposure is a fault.

		We are here via permission of the Superintendent, Palisades Interstate Park, Bear Mountain, Mr. Orth (914) 786-2701.
0.5	36.4	Return to bus; drive to top of hill, turn R past Fire station.
1.05	37.45	Intersection Rte. 9W; turn R (N, toward Haverstraw)
0.3	37.75	Passing Swartwout Lake (to L side of road)
1.2	38.95	Intersection N. Y. 303; continue on 9W
1.5	40.45	Intersection NY 304 (South Mountain Road), Short Clove (Long Clove quarry at top of Palisades Ridge to L)
0.2	40.65	Roadcuts on both sides; dolerite of Palisades sheet
0.2	40.85	Cuts of sandstone underlying Palisades Dolerite
0.55	41.40	Cuts in dolerite
0.05	41.45	Dolerite in cuts on L side of U. S. 9W
0.3	41.75	Traffic signal; New Main Street, Haverstraw
0.5	42.25	Junction U. S. 202; continue on U. S. 9W
1.5	43.75	Enter Village of Stony Point
1.0	44.75	Bridge over Pond Brook
0.05	44.8	Turn sharp R downhill to village park
0.25	45.05	STOP 2 Siltstones and associated rocks near base of Triassic sequence. These strata surely qualify lithologically as Brunswick Formation, yet they occur within a few hundred feet stratigraphically of the base of the Triassic succession. What is more, at this locality the distance to the Ramapo fault is only 3 miles, yet these strata exposed south of the creek are generally fine grained. The suggestion is that the Brunswick facies extends from the bottom to the top of the Triassic succession in areas close to the Ramapo fault. The light-colored materials have not been examined up close. They could be caliche zones (as seen in Connecticut and as described recently in Pennsylvania by J. D. Glaeser) or light-colored clasts of Paleozoic carbonate rocks. The creek was high during my previous visit; hence I have not been able to view them at close range. The strike and dip are important here; these beds are considered by me to be a part of the SW limb of the Danbury anticline. If that is true, then the strike should be about N45°W and the dip toward the SW.
0.25	45.3	Return to U. S. 9W; turn R (proceed N)
0.65	45.95	Turn R into local street
0.25	46.2	Pond on R lies in strike valley at base of Triassic; upland ahead is underlain by Paleozoic carbonate rocks (Tompkins Cove quarry is just over the hill to N). Turn L, uphill. STOP 3 Paleozoic carbonate rocks. If more time were available it would permit stopping in the quarry at Tompkins Cove. We can see enough here for our present purpose.
0.25	46.45	Intersection U. S. 9W-202; turn L (heading S)
0.15	46.6	Park on R in parking lot for Bluebird Restaurant. Walk along road to R to exposures of basal Triassic conglomerate. STOP 4. Limestone-pebble conglomerates within a few hundred feet stratigraphically of the base of the Triassic. Measure strike and dip.

		Return to bus; continue S on U. S. 9W-202.
3.0	49.6	Turn R (toward W), following U. S. 202
0.7	50.3	Power lines cross overhead
0.35	50.65	Enter Thiells quadrangle
2.45	53.1	Traffic signal, intersection N. Y. Rte. 45; end of Palisades sill in ridge at L
0.1	53.2	Cross under Palisades Interstate Parkway
1.4	54.6	Deep cut in till, Ladentown, near N end of a drumlin 1.3 miles long that is one of many in the SE corner of the Thiells quadrangle that trend N-S. This implies due N to due S ice flow here, a direction which contrasts with the N20°W to S20°E flow indicated by striations on the bedrock farther south. The significance of these two flow directions is not known by me at present.
0.3	54.9	Junction N. Y. Rte. 306; continue SW on U. S. 202 Ahead are the Ramapo Mountains, underlain by resistant Precambrian rock on the northwest side of the Ramapo fault. Judging by the almost total composition of Paleozoic carbonate rocks in the Triassic conglomerates, these Precambrian rocks were not exposed at the Earth's surface in many places until late in the Triassic Period, or even early in the Jurassic Period. Some local exceptions to this do occur; feldspars in the Brunswick Formation in Rockland County have been dated by K-Ar methods at 870MY and 930MY (Abdel-Monem and Kulp, 1968). These feldspars indicate that in at least one drainage basin feeding into the area of Triassic sedimentation, Precambrian rocks were exposed before the end of the Triassic Period. The Ramapo fault lies concealed within the valley along which the Mahwah River now flows (from NE to SW).
0.3	55.2	Dolerite on L side of road (I do not know its significance; my guess is that it is a fault slice of one of the sheets brought up on a narrow block bounded on one side by the Ramapo fault and on the other side by another fault, not previously named.)
0.95	56.15	Dolerite on R side of road
0.15	56.3	Conglomerate on R side of road (exposures described in detail by Carlston, 1946.)
0.1	56.4	More conglomerate on R
0.2	56.6	Conglomerate on R
0.4	57.0	Dolerite exposed on L.
0.9	57.9	Wesley Chapel, side road; park and walk along Rte. 202 in SW direction to cuts on both sides of road. STOP 5. Conglomerate. Stratigraphic position not known. Debris shed from rising Ramapo fault block that was active during Triassic sedimentation. Most clasts consist of Paleozoic rocks. See Carlston's paper (1946) for details.
		Return to bus and continue SW on U. S. Rte. 202
1.5	59.4	Enter Sloatsburg quadrangle
1.7	61.1	Enter Ramsey quadrangle
0.2	61.3	Lake Antrim on L; exposures of Precambrian gneiss on R. STOP 6. Precambrian rocks on NW side of Ramapo fault.
0.3	61.4	Cross beneath New York Thruway; continue SW on U. S. 202
0.4	61.8	Junction of N. Y. Rte. 59 entering from L
0.65	62.45	New York-New Jersey State boundary

0.05	62.5	Turn R; follow U. S. 202 southwestward, cross under RR.
0.3	62.8	Crossing Mahwah River, near junction with Ramapo River, which flows S out of the Precambrian Ramapo highland, then turns SW and follows the fault-line valley (Ramapo Valley).
0.7	63.5	Pass under Rte. 17
1.7	65.2	On R: main entrance to Ramapo College (Darlington)
0.3	65.5	Junction with N. J. Rtes. 2 and 3
1.4	66.9	Exposure on L of dolerite of Campgaw Mountain (another enigmatic body of igneous rock, possibly a fault slice of one of the other sheets).
3.4	70.3	Dolerite exposed on L side of road
0.5	70.8	Crossing under N. J. 208
0.2	71.0	Blinker light at RR crossing, Oakland
0.7	71.7	Enter Wanaque quadrangle
0.45	72.15	"T"-shaped intersection, junction Franklin Lakes Rd; turn R, following U. S. 202. Exposures ahead are part of a great "ramp" of till banked against the N side of the scarp underlain by the Second Watchung extrusive sheet.
0.45	72.7	Dolerite on L side of road; Second Watchung sheet.
0.15	72.85	Enter Passaic County.
1.2	74.05	Enter Pompton Plains quadrangle
0.5	74.55	Exposures of conglomerate lying between Second and Third extrusive sheets; on L side of road.
0.5	75.05	Dolerite; Third Watchung sheet
0.05	75.1	Grand Union parking lot; bus waits here while we walk to exposures. STOP 7. The extrusives here strike about NW and dip SW, on the flank of the Danbury anticline, according to me. Strictly speaking, only the Second Watchung sheet is part of the Danbury anticline. The Third Watchung sheet is folded somewhat differently; although the strike and dip of the Third Watchung sheet are the same here as those of the Second Watchung sheet, there must be a fault in between. I infer this fault to account for the differential folding of the two sheets; perhaps this fault is only a zone of decollement in the Brunswick beds.
		After leaving Grand Union parking lot, turn L onto Hamburg Turnpike, U. S. Rte. 202, and continue S.
0.5	75.6	Jct. Dawes Highway; follow 202.
0.35	75.95	Bear R on U. S. 202, Black Oak Ridge Rd
0.9	76.85	Pompton Plains Center Rd., bear L, staying on Black Oak Ridge Rd., which is U. S. 202
1.8	78.65	Traffic circle; follow U. S. 202 and N. J. 23 to S, leaving Black Oak Ridge Rd., and following Pompton Tpk.
1.75	80.4	Road curves R; traffic circle; bear L, keep on 202-23.
0.8	81.2	RR overpass (log from here on based on topographic maps)
0.15	81.35	U. S. 202 bears R; continue S on N. J. 23.
1.6	82.95	Intersection with U. S. 46; turn R, heading W on Rte. 46.
0.1	83.05	Passing RR tracks
0.7	83.75	Crossing Passaic River, 0.5 mi. S of confluence of Pompton River (which consists of united Ramapo, Wanaque, and Pequannock rivers).

0.9	84.65	Exit from U. S. 46 on R, to join Little Falls Rd. Cross over U. S. 46 and turn R at "T" intersection, proceeding SW on Little Falls Rd.
0.15	84.8	Turn L onto New Dutch Lane
0.7	85.5	"T" intersection; turn R onto Passaic Ave.
0.45	85.95	Enter Caldwell quadrangle
0.15	87.1	Greenbrook Rd. enters from L; continue SW on Passaic Ave. Passing Caldwell Wright airport
1.9	89.0	Intersection N. J. Rte. 506; continue on Passaic Ave., which now changes its name to Swamp Rd.
2.6	91.6	"T" intersection; turn L onto Eagle Rock Ave., Beaufort.
0.25	91.85	Turn R on road to quarry, Locust Ave.
0.25	92.1	Turn R on 2nd or 3rd dirt road - Go to crest.
		STOP 7, quarry in extrusive sheet and underlying sedimentary strata. I think this is the Third Watchung sheet, but not everyone is unanimous on this point, I gather. The Second Watchung sheet forms a dip slope on the high ridge whose crest is about 3 miles to the SE. The sheet at the quarry is along strike with the end of Towakhow Mountain, which projects upward from the sediment fill of Passaic River valley (capped by Hatfield Swamp). The quarry lies about 5 miles SE of the Ramapo fault. The Brunswick strata underlying the extrusive sheet (whichever one it is) are fine grained, and display various primary sedimentary structures. Some dinosaur footprints have been quarried here, but they are not usually visible <u>in situ</u>.
		The strata here are on the SW limb of the Montvale anticline, which plunges NW (that is, assuming this is the Third Watchung sheet). This anticline is part of the paired anticlinal-synclinal structure also known as Hook Mountain.
		Return to bus and retrace route to Jct. N. J. 506
0.25	92.35	At end of Locust Ave., turn L onto Eagle Rock Ave.
0.25	92.6	Turn R onto Swamp Rd. (West Passaic Ave.)
1.9	94.5	Intersection N. J. Rte. 506; continue on to NE
0.1	94.6	Turn L onto Clinton Rd.
1.0	95.6	Bear R; start curving entrace to eastbound U. S. Rte. 46.
0.7	96.3	Enter U. S. 46, eastbound.
0.7	97.0	Enter Pompton Plains quadrangle
2.2	99.2	Cross Passaic River.
0.8	100.0	Junction N. J. 23; continue E on Rte. 46
0.1	100.1	Enter Paterson quadrangle. View ahead through large gap in Second Watchung Mountain, through which Passaic River now flows.
0.7	100.8	Overpass for Nachpunkt Rd-Riverview Dr.; stay on U. S. 46
0.6	101.4	Overpass for Union Ave.; continue on U. S. 46.
0.4	101.8	Exit ramp on R for McBride Ave.-Little Falls Tpk., Little Falls.
0.05	101.85	Bear L on ramp to turn L onto McBride Ave.
0.05	101.9	Pass under Rte. 46, following McBride Ave. toward NE.
0.65	102.55	Bear R after passing school on R.
0.3	102.85	"T" intersection, with Browertown Rd. entering on R; turn L, staying on McBride Ave.
0.7	103.55	Intersection N. J. 62, Totowa Rd., on L; continue on McBride Ave., now also N. J. 62. Passaic R. on L

(End of log based only on topographic quadrangle maps)

0.5	104.05	Monument in Pennington Park on L
0.15	104.2	Exposure of First Watchung sheet by Texaco Station on R.
0.35	104.55	Traffic signal for Spruce St.; turn L on Spruce St. cross bridge over Passaic R.; falls on R.
0.2	104.75	Dairy Queen on R; turn R in street just beyond Dairy Queen.
0.1	104.85	Exposures on L are First Watchung sheet; just beyond, turn R and park at pumping station.

STOP 8. Walk down gravel road toward river on L; exposures of First Watchung extrusive sheet and red pebbly sandstone of Brunswick Formation, of which about 20 ft. are exposed. A zone about 8 ft. thick near the top contains scattered well-rounded pebbles of Paleozoic sandstone and white carbonate rocks. The pitted surface of the exposure has resulted from dissolution of the carbonate pebbles.

The contact of the igneous rock with the sandstone has created negligible contact effects; no bleaching of the sandstone is apparent. The contact surface follows a small bench; trees have grown along the contact, sending their roots into the rock where ground water seeps out.

The lower 30 ft. of the igneous rock displays excellent columnar joints. This zone if regular joints is overlain by a zone of irregular joints, which continues to the top of the cliff. The contact of these two zones gives the appearance of two distinct cooling units, but the rock in both zones above and below the contact is porphyritic and shows no concentration of vesicles or other features that commonly occur along the contact between one flow sheet and a second.

The falls have eroded along vertical joints that are oriented about N-S.

Across the river by the factory, the contact between the igneous rock and the underlying sandstone lies about at water level, perhaps 20 feet or so lower than at the exposure on our side of the river. A fault has been inferred to account for this difference in level of the contact.

This is the last stop; re-board bus and return to campus.

On leaving parking lot, turn L, pass Dairy Queen

0.2	105.05	Turn L onto Spruce St.
0.1	105.15	Across bridge; traffic signal; turn R into McBride Ave. N. J. Hwy 62, which follows along Passaic R. upstream from the falls
1.0	106.15	Intersection Totowa Rd, on R.
0.1	106.25	First Watchung sheet exposed on L.
0.8	107.05	Passing under I80; exposure of First Watchung sheet on L
0.2	107.25	Where McBride Ave. turns R, continue straight ahead, on Browertown Rd. First Watchung sheet on L; dips toward road (i. e., NW, on limb of "Taconic geanticline")
0.6	107.85	Stop sign; intersection of Lackawanna Ave.; continue straight on Browertown Rd.
0.3	108.15	Leaving West Paterson; more exposure of First Watchung sheet on L.

0.1	108.25	Junction U. S. 46; go under Rte. 46 and turn R on ramp for access to eastbound lane (just before Rte. 46 is the Great Eastern Discount Center on R)
0.4	108.65	Lower Notch Rd.
0.5	109.15	~~Stay on~~ U. S. 46; on R ramp to Great Notch, Cedar Grove; exposure of First Watchung sheet on R. Enter Orange quadrangle
0.45	109.6	Borough boundary.
0.15	109.75	Jct. Rtes U. S. 46 and N. J. 3; bear R on N. J. Rte. 3
1.6	111.35	Passing under Garden State Parkway
2.2	103.55	Exposures of Brunswick Fm. near jct. with N. J. 7
1.6	105.15	Crossing Passaic River Enter Weehawken quadrangle
0.1	105.25	Turn off N. J. 3 on exit for Riverside Avenue, Northbound
0.6	105.85	Riverside Avenue becomes Jackson Avenue
0.2	106.05	Turn R into W. Passaic Avenue
0.4	106.45	Campus gate of Fairleigh-Dickinson College on L.

End of road log.

Acknowledgment. I thank Ms. Sharon Labrot, a student at Barnard College, and Dr. Carlyle Gray, for their assistance in compiling this road log. Thanks go also to Steve Averill, for making the arrangements for the trip, obtaining permission to enter the quarry at Beaufort, and for his general good cheer while he sweated out the delivery of this material.

Mineralogy-Petrology Trip to Northwestern New Jersey

A. Alkalic Igneous Rocks of the Beemerville Area
B. Franklin Zinc District

by

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Introduction

This excursion into Sussex County New Jersey provides an opportunity to observe and collect some uncommon minerals and rocks in an otherwise "ordinary" segment of the Appalachian Mountains. We will traverse three of the four physiographic provinces of New Jersey (Figure 1). The field trip route lies in glaciated terrain. We will be crossing faults, folds and unconformities in igneous, metamorphic and sedimentary rocks. The accompanying sketch maps, cross-sections and text are intended to serve as an introduction to the unique Franklin ore body and to the alkalic rock complex near Beemerville. A bibliography is included. The trip progresses from the Triassic Lowlands province to the New Jersey Highlands (Franklin) into the Ridge and Valley province (Beemerville).

Triassic Lowlands

The region underlain by rocks of Triassic age (about 180-225 million years old) is generally of low and subdued topography, though it contains curvilinear hills (mountains) underlain by more resistent igneous rocks. The Lowlands, known as the Newark Basin, lie in a down-faulted basin within the New England province. The western border of the basin is an eroded fault scarp; movement on the fault has continued throughout the time of deposition of the Triassic beds and may be continuing today at a diminished rate. Figure 2 shows a generalized profile of the Lowlands.

The sedimentary rocks of the Lowlands consist of non-marine shales, siltstones, sandstones, arkoses and conglomerates (fanglomerates) along the border fault. The total thickness of these deposits is 4900-6000m. Interlayered with the sedimentary units are three basaltic lava sheets which form the three ridges of the Watchung Mountains. 1st Watchung Mountain is 600-650 feet thick; 2nd Watchung Mountain is 700-900 feet thick and 3rd Watchung (Hook) Mountain is about 300 feet thick. Each mountain consists of multiple superposed lava flows. Intrusive igneous rocks of basaltic composition comprise the Palisades sill and smaller sills and plugs in the basin.

The deformation of the Newark Basin involved these events (Van Houten, 1970, p. 330)

1. Uplift of an east-southeast borderland during the entire basin-filling episode, supplying sodium-rich detritus.
2. Continuous down-faulting along NW border producing regional NW gradient in the basin, and a NW upland that shed coarse Paleozoic detritus in alluvial fans along the border fault scarp. Toward end of this episode sills and lava flows were emplaced.
3. Deformation of all major faults and folds and tilting of the basin after major deposition and igneous activity.
4. Emplacement of dike swarms.

Agriculture remains fruitful in some of the Lowlands, but has given way to the residential, industrial and commercial enterprises of megalopolis. The lowlands is the most thickly populated region of New Jersey, contributing to its being the most densely populous state. The rock strewn Watchungs and the flood-prone swamps and meadowlands- remnants of Glacial Lakes Passaic and Hackensack, remain obstacles to settlement.

New Jersey Highlands

The Highlands are an extension of the New England Province, and consist primarily of metamorphic rocks of Precambrian age. Gneiss is the predominant rock type, including: pyroxeue-quartz-feldspar gneiss, hypersthene-quartz-plagioclase gneiss, biotite-quartz-feldspar gneiss, epidote-scapolite-quartz gneiss, syenite gneiss and amphibolite; marble and schist are not widespread. Most of the gneisses are metasedimentary (e.g. Baker and Buddington, 1970). The Precambrian igneous rocks present include pyroxene and/or hornblende granites and gneissic granite, alaskite and pyroxene syenite.

The major structures of the Highlands gneisses are a series of northeast-trending isoclinal or nearly isoclinal folds overturned to the NW and faults. Fold axes and mineral elongations plunge 10-30° NE (e.g.: Smith, 1969, Baker and Buddington, 1970). Faulted within the 1,000 million year old crystalline highlands are remnants of formerly more continuous sedimentary strata of Paleozoic age, mostly between 440 and 350 million years old. One large zone of Silurian-Devonian rocks, the Green Pond Mountain belt, crops out along the center of the New Jersey Highlands (Figure 1).

The regional metamorphic facies of the Highlands appears to increase in grade from the sillimanite-almandine-orthoclase range of the amphibolite facies, southeasterly to the hornblende granulite range of the granulite facies (Baker and Buddington, 1970).

The following age sequence is suggested for the gneisses (Smith, 1969, p. 45):

1. Hypersthene-quartz-andesine [plagioclase] gneiss
2. Amphibolite-marble-potassic gneiss assemblage
3. Sodic gneiss

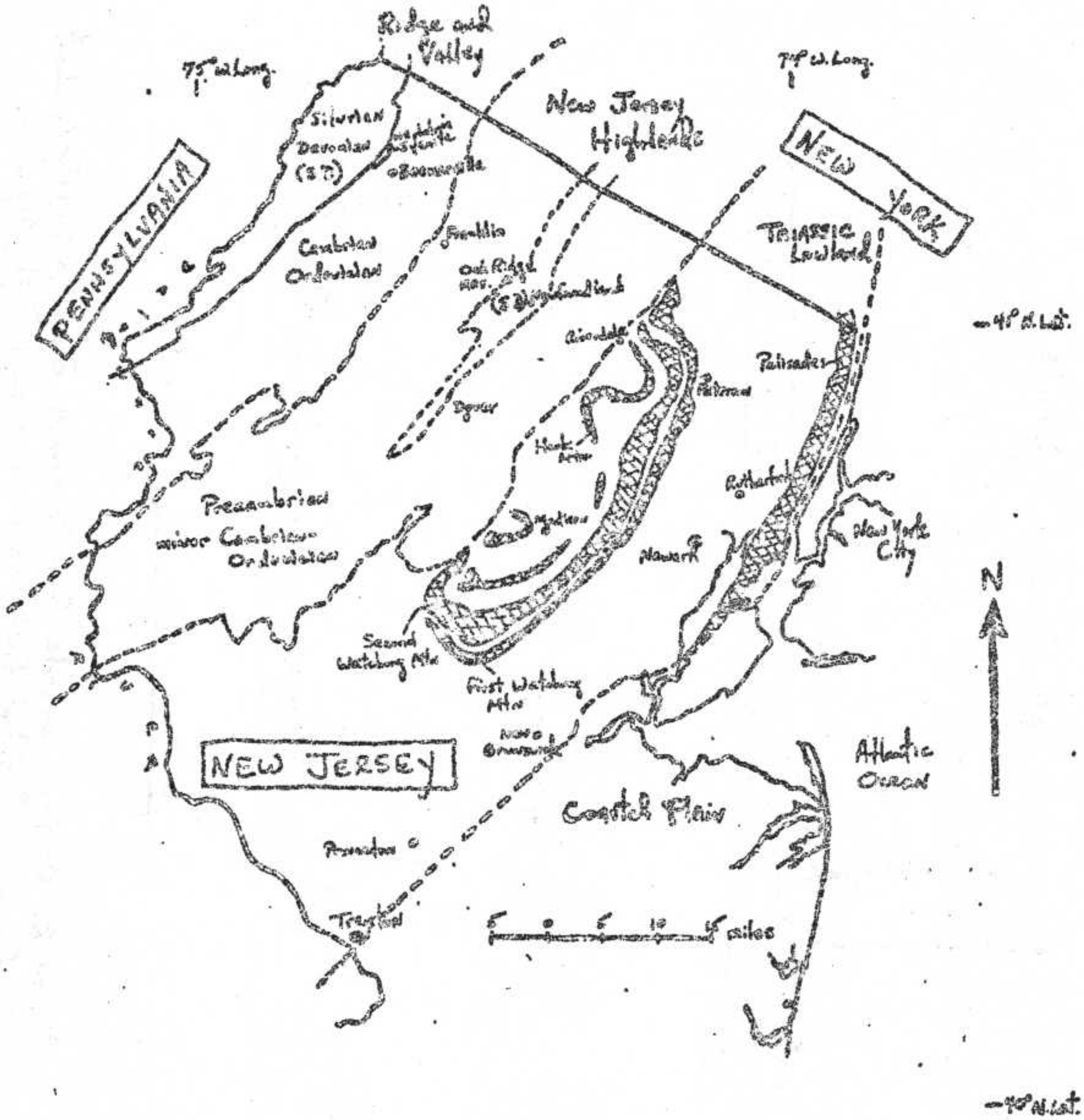
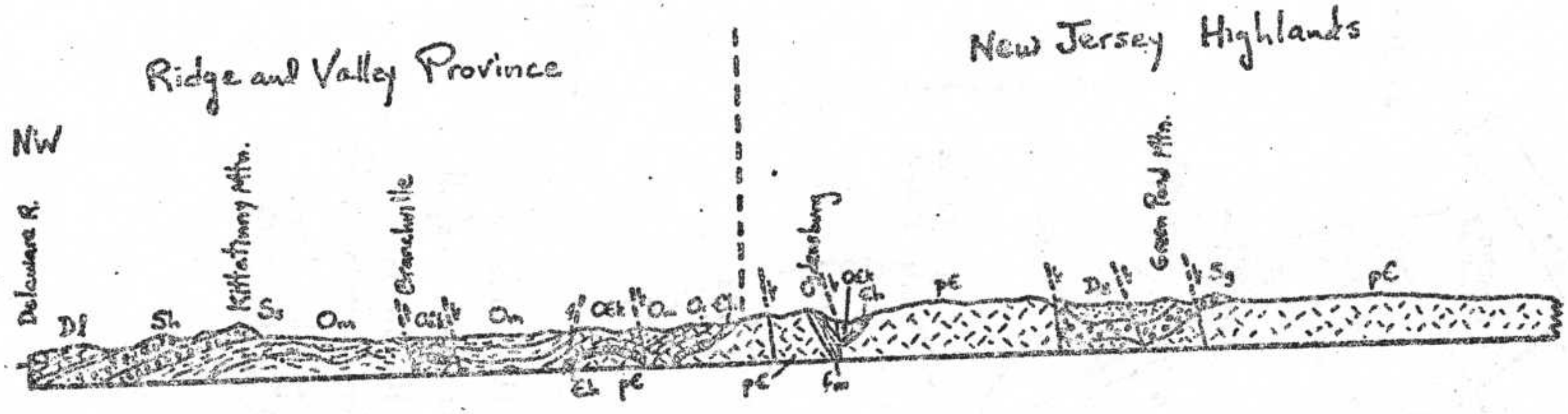


Figure 1. Location map of northern New Jersey showing boundaries of physiographic provinces, the basaltic rocks of Triassic Lowlands, the Silurian-Devonian inlier (SD) in the New Jersey Highlands, the nepheline syenite mass in the Ridge and Valley Province and the towns encountered on the field trip route.



Legend

- Ꞧb Brunswick Fm.
- Ꞧs Stockton Fm.
- Ꞧbs basalt
- Ꞧd diabase
- Dl Limestones
- Sh High Falls Fm.
- Ss Shawangunk Cgl.
- Ds Sandstones
- Sg Green Pond Mtn. Cgl.
- Om Martinsburg Fm.
- Oj Jacksonburg Ls.
- Ock Kittatinny Ls.
- Ch Hardyston Ss.
- pC Precambrian rocks
- fm Franklin Marble
- Onyc New York City Gp.
- sp serpentine

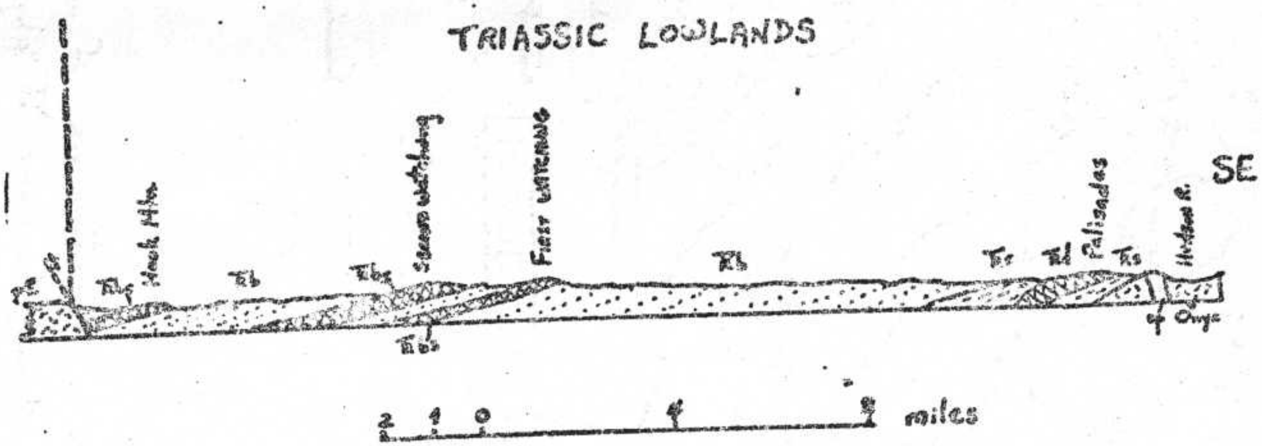


Figure 2. Geologic profile from Dingman's Ferry to Hoboken, about five miles South of field trip route (modified slightly from Geologic Map of New Jersey, 1950, M.E. Johnson, N.J. Geol. Survey Atlas Sheet 40).

Iron mining began in the Highlands in 1710; limonite, hematite and magnetite deposits were worked to a peak of activity in the 1880's (136 mines); in 1956 only four magnetite mines were working; not one is presently active (Widmer, 1964, p. 29). Widmer (1964, ch. 2) relates the development of the iron mining industry and the topography, esp. scarcity of E-W cross-valleys and prominence of extensive linear NE-trending valleys, to Revolutionary War history and settlement patterns. Much of the Highlands is sparcely settled woodlands.

Ridge and Valley Province

The Ridge and Valley Province in New Jersey is underlain by Ordovician to Devonian sedimentary rocks dipping gently westward. The Martinsburg Formation underlies most of the eastern part of the Province forming a low rolling hilly section, the Great Valley, between Kittatinny Mountain and the Highlands (Figure 2). The Ordovician Martinsburg consists of grey to black slate interbedded with graywacke sandstone and siltstone. Kittatinny Mountain is composed of the Silurian Shawangunk Conglomerate consisting mainly of light grey quartzite and conglomeratic quartzite. The Shawangunk unconformably overlies the Martinsburg (Drake and Epstein, 1967).

Epstein and Epstein (1969) consider different horizons in the Shawangunk to represent alluviated coastal plain, tidal flat and barrier barbeach deposits. The Martinsburg represents flysch-type sedimentation representing Taconic orogenic activity (McBride, 1962).

The Ridge and Valley of New Jersey is sparcely settled; the valleys are farmed.

Alkalic Igneous Rocks of the Beemerville Area

Main mass.
The main mass of alkalic rock is approximately 1 3/4 miles long and 1/4 mile wide trending NE and situated about 1 1/2 miles NW of Beemerville, Sussex County, New Jersey (Figures 1, 5, 6). It is poorly exposed, contacts have not been reported, and mapping must be based largely on float. The main mass is predominately nepheline syemite; it is cut by at least one dike of lencite tinguaite on the south end (Wolff, 1902) and at least one volcanic pipe-breccia in the northern end (Spencer and others, 1908; Figure 5).

Dikes.
Syenatic and lamprophyre dikes tens to a few thousands of feet long and inches to tens of feet wide occur to the east and southeast of the Beemerville mass (Figure 5). Table 1 defines the rock names used in this guide. The dikes have NE or NW strikes which is interpreted as a crude concentric and radial dike-swarm arrangement (Spencer and others, 1908). A camptonite dike exposed at the Trotter dump (STOP 7) 10 miles to the SE and other lamprophyres in the Hamburg-Franklin-Woodruffs Gap area are also apparently satellite intrusions of the Beemerville mass. Wolff (1908) called attention to a zonal distribution of the satellite intrusions as follows: main mass is bordered on east and south by ouachitite volcanic pipe-breccias; further to SE dikes are nepheline syenite and bostonite; still further to SE are lamprophyre dikes.

Table 1. Beemerville Rock Names Defined
(see Moorhouse, 1959 and Williams and others, 1954)

Bostonite - a syenitic dike rock characterized by a flow texture in which lath-shaped feldspar grains are arranged in rough parallelism or in radiating patterns. Feldspars are alkalic. Potash feldspars may be perthitic. Biotite, hornblende or pyroxene are the scarce ferromagnesians. Quartz is almost always present in small amount, usually in matrix. Secondary carbonate, chlorite, and epidote are almost always present.

Foyaite - a nepheline syenite with orthoclase as the feldspar in about same amounts as nepheline,and hornblende and augite as the principal dark minerals.

Lamprophyre - A dike or small intrusion of an alkalic prophyritic dark-colored rock with phenocrysts of biotite, aegerine-augite or hornblende in a fine-grained matrix which may contain alkali feldspar, nepheline or analcite in addition to the mafic minerals.

Camptonite - an alkali amphibole lamprophyre with plagioclase
Fourchite - a pyroxene lamprophyre without feldspar
Minette - a biotite lamprophyre with orthoclase
Ouachitite - a feldspar-free biotite lamprophyre

Leucite tephrite (leucite basalt) - leucite, pyroxene, plagioclase

Nepheline syenite- more than 2/3 of rock is alkali feldspar or perthite. and nepheline with augite or aegerine-augite, amphibole and biotite; accessary minerals: sodalite, noselite, hauynite, scapolite, cancrinite, calcite, zircon, sphene.

Tinguaite - a phonolite dike; fine grained nepheline syenite.

Breccia.

The ouachitite pipe-breccias appear to be volcanic plugs or necks. Six occurrences have been reported (Spencer and others, 1908; Figure 5). The ouachitites are "choked" with xenoliths consisting mainly of Martinsburg shale and siltstone up to 10 inches long-dimension and of lesser quantities of limestone, biotite-feldspar gneiss, quartzite (?) and syenite (?). Tabular-shaped xenoliths, mainly Martinsburg rocks, show a parallelism at some outcrops which probably reflects flow layering.

Discovery.

The Beemerville mass was discovered by E. Hauesser, field geologist for the State Survey (Cook, 1858). Hauesser described the mass as consisting of a porphyritic hypersthene rock; he also described a hornfels contact zone in the surrounding Martinsburg shales. Emerson (1882) first recognized nepheline syenite and believed the mass to be a dike. Kemp described Rutan's Hill, the largest pipe-breccia outcrop (Figure 5) and others; he noted the mineral inhomogeneity of the nepheline syenite main mass and described satellite dikes of leucite tephrite and fourchite among others mentioned above.

Age.

The intrusions cut the Ordovician Martinsburg Formation, but not the unconformably overlying Silurian Shawangunk Conglomerate. Paleomagnetic (Proko, 1971) and radiometric evidence (Zartman and others, 1967) verify an (Upper) Ordovician age for the nepheline syenite main mass and the Rutan Hill breccia, i.e., 435 $\pm$ 20 million years old.

Subsurface.

Gravity data (W. E. Bonini, 1972, personal communication) and regional structural evidence (Spink, 1972) suggest that the nepheline syenite main mass is the outcropping portion of a larger pluton the bulk of which lies to the southeast in the subsurface beneath the town of Beemerville. Figure 3 illustrates some points about the area that require some kind of verification.

Chemistry.

Table 2 is included to show that the Beemerville nepheline syenite is similar to the average nepheline syenite; the Beemerville mass (and tinguaite dikes not shown on table 1) is relatively high in alkalis (cf. granodiorite which is near average composition of continental crust); the lamprophyres are considerably richer in iron and magnesium than are the syenites.

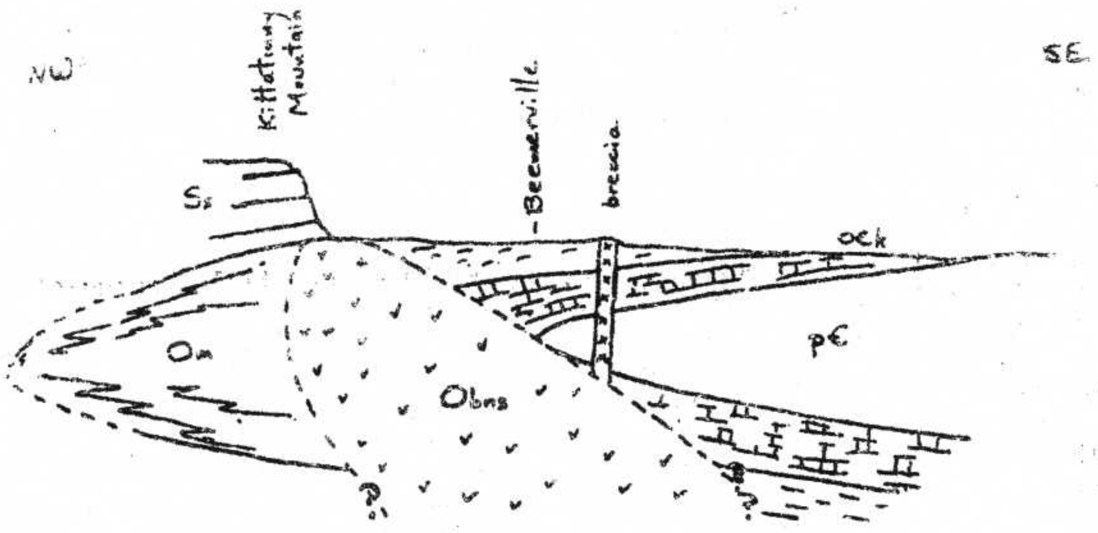


Figure 3. Diagrammatic sketch combining several concepts of Beemerville area. (1) main mass of Beemerville nepheline syenite beneath town of Beemerville, (2) pipe-breccia shale, limestone, gneiss xenoliths are derived from subsurface stratigraphic units comprised of these rock types, (3) surface rocks are in upper limb of the Musconetcong nappe described further southwest (Drake, 1969). [pЄ - Precambrian gneisses; OЄk - Cambro-Ordovician Kittatinny Limestones; Om - Ordovician Martinsburg Formation; Obns - Ordovician nepheline syenite; Ss - Silurian Shawangunk conglomerate].

Petrogenesis.

Turner and Verhoogen (1960, p. 394-398) discuss the origin of nepheline syenites. They may originate as follows:
(1) fractional crystallization of undersaturated (alkali olivine) basalt magmas.
(2) differentiation from a silica-saturated syenite-monzonite magma
(3) assimilation of limestone by granitic or granodioritic magma
(4) fusion of crustal material with early separation of the melt (anatexis)
(5) metasomatism of dolomitic limestone
The question of origin of the Beemerville alkali igneous complex is open at the present time.

Franklin Zinc District.

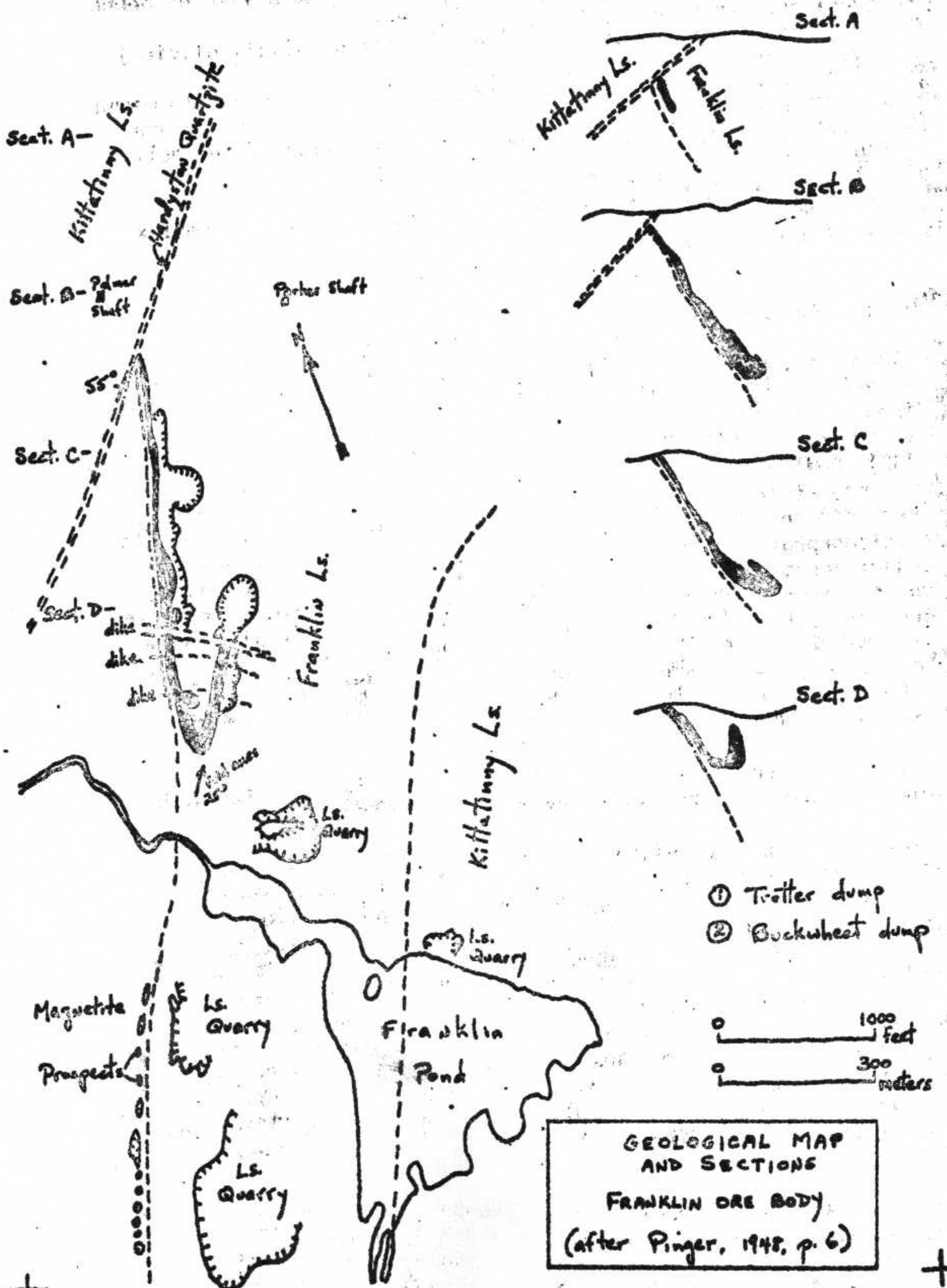
The Franklin Limestone (Spencer and others, 1908; numerous reports) is a marble. "The rock is a white to gray, coarse to locally fine-grained crystalline marble, which varies in magnesium content from very low to an almost pure dolomite " (Hague and others, 1956, p. 438). Dolomite bands alternate with calcite bands. Quartz sand layers may represent original sedimentary bedding. The marble grades into gneiss on either contact, indicating that the contacts are metamorphosed gradational sedimentary contacts. The most abundant accessory minerals in the marble in order of decreasing abundance are: graphite, tremolite, phlogopite, pyrite, pyrrhotite, quartz and talc; diopside, chondrodite and norbergite also occur in the marble. The calcite crystals in the coarse-grained bands commonly are visibly twinned, with twin planes parallel to the long diagonal of cleavage rhombohedrons. Calcite cleavage planes are sometimes bent or kinked.

The marble is older than 1100 million years, because it is cut by a pegmatite dike of that age (Long and Kulp, 1962).

The ore apparently was discovered by Dutch settlers at about 1640. In the 1700's the tract was unsuccessfully developed as a copper and iron mine. The red massive <u>zincite</u> (ZnO) was mistaken for <u>cuprite</u> (Cu_2O) and the black octahedral <u>franklinite</u> ($ZnFe_2O_4$) was mistaken for <u>magnetite</u> (Fe_3O_4)! The New Jersey Zinc Company first exploited the ore in 1850. In 1954 the Franklin ore-body was depleted and the mine shut down. The Franklin Mineral Museum and Replica Mine was created in 1954 by the local kiwanis. The Museum also monitors collecting at the Buckwheat open pit. The similar ore-body 3 miles south of Franklin (Sterling Hill) was exploited in 1877 and the operation is still active. The Trotter shaft was sunk in 1880 (Widmer, 1964).

More than 200 mineral species have been reported from the Franklin-Sterling Hill mines; about 3 dozen of the minerals fluoresce. About 2 dozen of the total are found nowhere else on earth (including 2 of the 3 principal ore minerals, franklinite and zincite).

Figure 4.



GEOLOGICAL MAP AND SECTIONS

FRANKLIN ORE BODY

(after Pinger, 1948, p. 6)

The average composition of the Franklin ore was as follows:

Franklinite	43	volume %
Willemite	26	"
Zincite	1	"
silicates	5	"
calcite	25	"
	100	"

(Palache 1935, p. 17).

The average chemical composition of the ore was as follows:

ZnO	31	weight %
FeO	25	"
MnO	10	"
SiO_2	9	"
$CaCO_3$	25	"
	100	"

(Palache 1935, p. 17).

The ore assemblages are: franklinite-calcite; willemite-franklinite-calcite; willemite-zincite-franklinite-calcite (Wilkenson, 1962). Willemite formed before franklinite and zincite (Metsger and others, 1958; see Ries and Bowen, 1922).

The origin of the unique zinc-manganese ore is not known. Five groups of theories have been proposed (Palache, 1935, p. 23-24): (1) Magmatic injection (Spencer and others, 1908; Spurr and Lewis, 1925) - the banded ores are considered to have been crystallized from a zinc-manganese-rich melt; each band is therefore a vein; there is no igneous textural evidence or suitable geochemical theory to support this idea;
(2) Sedimentary deposition (Kitchell, 1855) - ore bands are considered to have been primary zinc-and manganese-rich sedimentary beds in the original limestone; does not explain "off-shoots" of orebody;
(3) Contact metamorphism (Kemp, 1893; Nason, 1894) - explains local skarn assemblages adjacent to pegmatites, but does not account for ore body;
(4) Hydrothermal replacement (Ries and Bowen, 1922) - does not account for source of metals;
(5) Metasomatic replacement (Palache, 1935) - postulates a metal source as "a previously existent mass of mixed sulfides" (ibid., p. 23). Metasomatism yielded hydroxides of zinc, iron and manganese and zinc and manganese carbonates. The present ore minerals, it is presumed, developed after regional metamorphism which caused dehydration and recrystallization of the metasomatic deposits.

Table 2. Chemical Composition of Some Igneous Rocks

	Nepheline Syenite	Nepheline Syenite	Nepheline Syenite	Grano-diorite	Camptonite	Ouachitite
SiO_2	47.19	53.56	55.38	66.88	40.71	40.47
TiO_2	2.16	-	.66	.55	-	-
Al_2O_3	23.01	24.43	21.30	15.66	19.26	11.86
Fe_2O_3	3.11	2.19	2.42	1.33	7.46	] 17.44
FeO	2.23	1.22	2.00	2.59	6.83	
MnO	.16	.10	.19	.07	.18	-
MgO	1.07	.31	.57	1.57	6.21	3.10
CaO	2.93	1.24	1.98	3.56	11.83	16.80
Na_2O	7.97	6.48	8.84	3.84	1.80	1.90
K_2O	8.23	9.50	5.34	3.07	3.26	4.21
H_2O	.59	.93	.96	.65	1.53	3.60
P_2O_5	.39	-	.19	.21	-	-

(1) Beemerville main mass; Aurousseau and Washington (1922)
(2) Beemerville main mass; Wolff (1908)
(3) Average of 80 worldwide; Nockolds (1954)
(4) Average of 137 worldwide; Nockolds (1954)
(5) Franklin dike, Trotter dump; Wolff (1908)
(6) Rutan's Hill; Kemp (1889)

Acknowledgments

I am grateful for the support and services rendered to me in the preparation of this field guide: secretarial- Connie McGoff and JoAnne Carideo, Dept. of Earth Science, FDU, and my wife, Myrna; field assistance- Mike Lynch-Blosse, Brenda Jogan and Bill Rittschof, earth science students at FDU; and thin sections- Doug Rhett, Dept. of Geology, Rutgers University. I appreciate the discussions and varied knowledge contributed by my colleague, Dr. Paul S. Boyer. I dedicate this guide to Dr. Kurt E. Lowe, City College of New York, whose teaching and study of the Highlands has always been an inspiration.

Road Log

Mileage	
0.0	Fairleigh Dickinson University - Rutherford. Start mileage on Passaic River bridge. Observe Triassic Lowlands: urbanization on floor of ancient glacial Lake Hackensack.
4.8	Jct. rte. 3 and U.S. 46, west on U.S. 46. Observe First Watchung Mountain to north and west. Large quarry visible to north exposes red shale of the Brunswick Formation in contact with the overlying lower flow unit of the 600-650 feet thick basaltic sheet; note columnar jointing in outcrops along U.S. 46.
7.4	Jct. U. S. 46 and Passaic River. Begin cut through the 700-900 feet thick Second Watchung Mountain; basalt outcrops show columnar jointing.
8.8	Jct. U. S. 46 and rte. 23, north on rte. 23. Lowland is floor of ancient glacial Lake Passaic. The curving ridge to the north and west is Hook Mountain (Third Watchung); it consists of about 300 feet of basalt.
10.4	Mountainview. Drive through water gap in Hook Mountain, back onto floor of Lake Passaic.
15.6	Jct. rte. 511A and rte. 23. Begin ascent of Ramapo fault scarp separating Triassic Lowlands to east from Precambrian New Jersey Highlands to west. Outcrops of darker gneisses are hornblende gneisses and amphibolites; lighter rocks are quartz-feldspar $\pm$ pyroxene$\pm$biotite; pink and black rock is hornblende granite.
25.1	Jct. Echo Lake Rd. and rte. 23. Meander in Pequannock River marks the separation of the Precambrian gneisses from the Silurian-Devonian Green Pond Mountain inlier. Copperas Mountain to left (west) and Kanouse Mountain to right (north) are underlain by Silurian Green Pond Conglomerate (see Finks, 1968, for guide to this area).
28.9	Oak Ridge Reservoir. Cross high-angle border fault separating Paleozoic inlier from Pre-cambrian gneisses. Eroded fault scarp visible to the left (SW) forming west shore of Reservoir. (see Baker and Buddington, 1970, for geologic map of route between Oak Ridge Reservoir and Franklin).

34.9	Jct. rte. 517 and rte. 23. Cambro-Ordovician Kittatinny Limestone inlier begins, ends near Franklin High School; in Franklin marble to Hardystonville.
36.4	Hardystonville. Inlier of Kittatinny Limestone begins; ends at Hamburg. Much stratified drift plains and kames in this area (north of terminal moraine).
41.0	Jct. Lewisburg Rd. (rte. 565) and rte. 23. Left on Lewisburg Rd. Area is underlain by Martinsburg Formation and is veneered with stratified drift-typical kame and kettle topography.
43.3	Jct. rte. 565 and rte. 565 Spur; straight on rte. 565 spur.
46.1	View of Kittatinny Mountain.
46.3	Jct. rte. 565 Spur and rte. 519. Turn right. Rutan's Hill just ahead.
48.6	Left on Nielson Rd.
49.0	Park on right point where road levels off.

STOP 1. RUTAN'S HILL. OUACHITITE PIPE-BRECCIA.

Largest volcanic pipe-breccia in the alkalic igneous complex (Figure 5). Dated 435 20 million years (Zartman and others, 1967). Climb to outcrops on north slope. Use buddy system when scrambling over or under barbed-wire fences. Rock matrix is ouachitite with abundant biotite phenocrysts. Xenoliths of Martinsburg Formation(?) are abundant with biotite gneiss and limestone xenoliths also present. Is flow layering present? Sedimentary rock inclusions have thermally metamorphosed rinds (hornfels). A supposed "carbonatite" reported from the east side of the Hill appears to be a carbonate-rich ouachitite; it contains kink-banded biotite and calcite with bent twin lamellae. Material in the stone fences and float includes bostonite, syenite and porphyritic volcanic rocks.

Continue southwest on Nielson Road.

50.4	Park on right between the two houses. Walk up path and pasture on N side of stream.

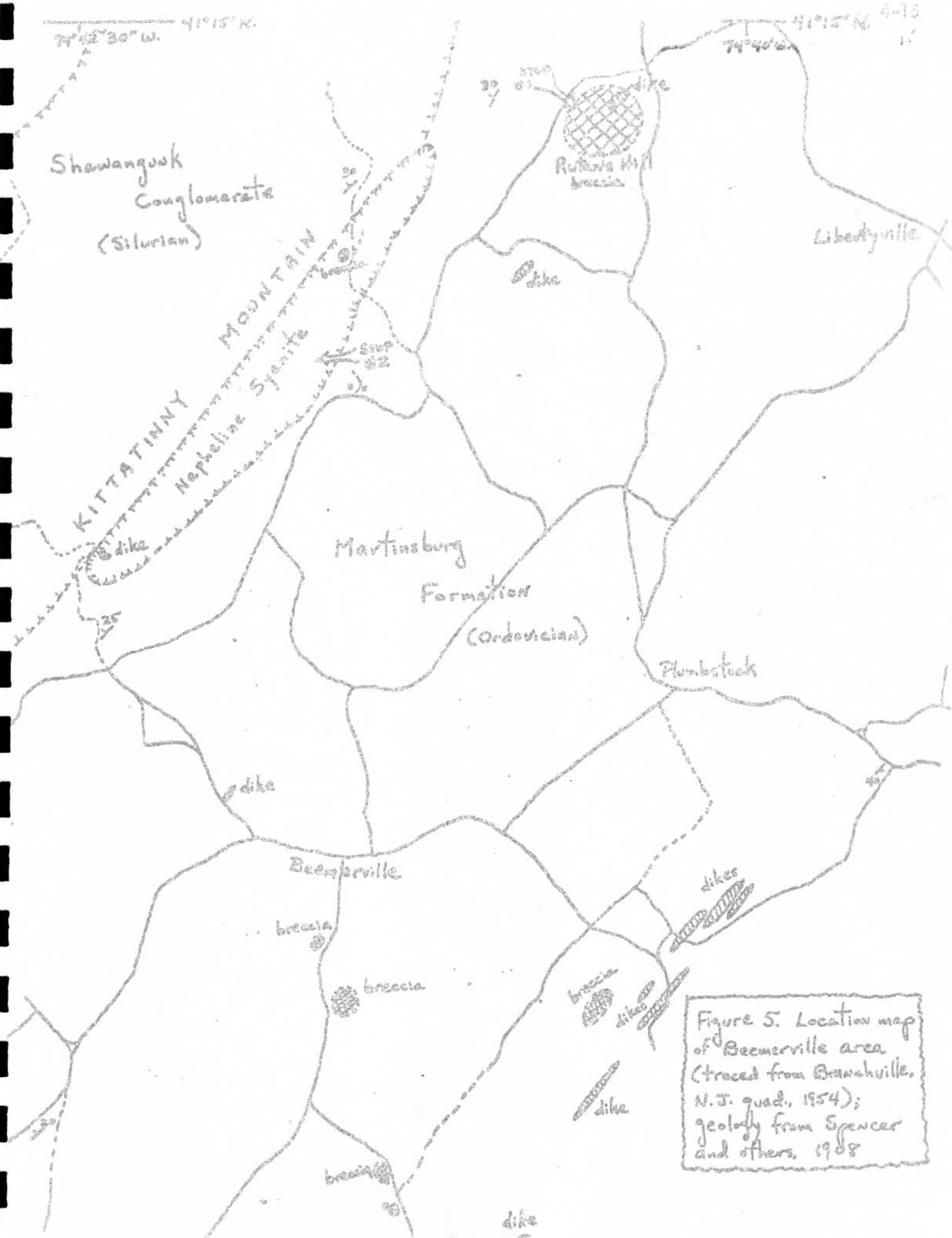


Figure 5. Location map of Beemerville area (traced from Branchville, N.J. quad., 1954); geology from Spencer and others, 1908

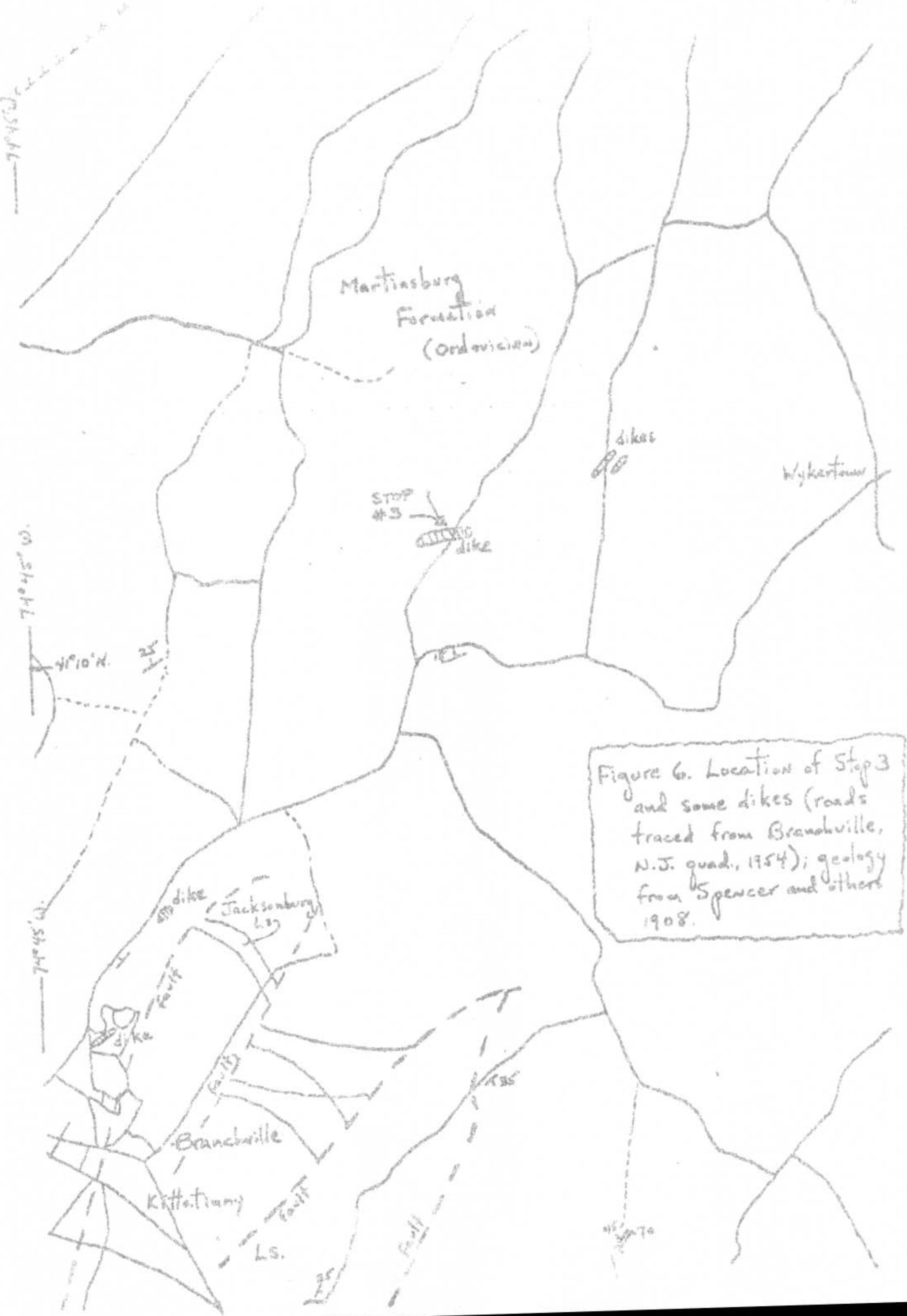


Figure 6. Location of Stop 3 and some dikes (roads traced from Branchville, N.J. quad., 1954); geology from Spencer and others 1908.

STOP 2. NEPHELINE SYENITE MAIN MASS.

Outcrops are scattered knobs jutting out of the pastures. The textural variation of the syenite is interesting. The minerals present are as follows: nepheline, orthoclase, aegerine-augite, biotite, sphene, apatite, magnetite and zircon (see Iddings, 1898, and Wolff, 1908). Tinguaite dikes cut the main mass. Ouachitite breccia float occurs about 200 yards north of here at about the 1200 feet elevation. Continue uphill to the talus slope of Shawangunk Conglomerate; bear SW and follow path along stream back to bus.

Continue SW on Nielson Road.

51.8 Jct. Crigger and Nielson Roads; turn left. If we turned right, up Kittatinny Mtn., we'd have seen an 8-inch dike in glacially polished Martinsburg shale and lots of boulder float of syenite. Very coarse grained syenite float with 2-inch long Carlsbad twinned orthoclase was observed.

52.5 Turn left on rte. 519 into Beemerville. Rest Stop at Space Farms and Zoo.

52.8 Turn right onto Wykertown Rd. at Sunoco station.

53.8 Outcrop in the pasture on right, just before coming to small pump-house, is a ouachitite pipe-breccia with flow-layered xenoliths; some Martinsburg (?) inclusions are about 10 inches long.

54.9 Take right fork.

55.2 Take left fork, then bear right.

55.6 Turn left

56.5 Park just beyond hillcrest on left and walk back to the outcrop.

STOP 3. NEPHELINE SYENITE DIKE AND MARTINSBURG FORMATION.

The ridge crossing the road is held up by a dike of nepheline syenite. Pockets of natrolite-andradite-allanite occur in the rock (Milton, 1952). The dike exhibits a closely spaced cleavage which trends N 35 W and dips 70 S.

The Martinsburg rocks show beddingdipping 15 SE and slaty cleavage dipping 40 SE. Where and what is the nearby fold? Is this dike-ridge due to contact metamorphism of the Martinsburg Formation? The steep west bank of the dike is eroding rapidly by mud flow; note spheroidal weathering.

Continue southward and bear right at nearby stop sign.

57.8 Straight on to rte. 519.

58.3 On left starts a quarter of a mile outcrop of Martinsburg shale and sandstone. Bostonite dikes have been reported from the area. Only one appears on Figure 6. It is exposed on the south slope on which stands the large building just beyond this outcrop.

58.6 Enter Branchville

59.1 Left on Broad Street

70.0 Straight on U.S. 206

70.4 Jct. U.S. 206 and rte. 15. Straight on rte. 15(S).

72.0 Kittatinny Limestone

73.2 Jct. rte. 15 and rte. 94. Turn left

78.5 Right fork to Franklin.

80.0 Turn right on Fowler St.

80.3 Turn right onto Wildcat Rd.

80.5 Cut in Cambro-Ordovician carbonates to left. "These may be th base of the Upper Cambrian Pine Plains Formation. The light-weathering dolomite is interbedded with thin, ripple-marked beds of quartz-sandstone. Oscillation and interference ripples are beautifully displayed both on bedding surfaces and in cross-sections" (Finks, 1968, p.144).

80.9 Park in Metaltec Laboratories lot. Walk back (north) on Wildcat Rd. .1 mile.

STOP 4. HARDYSTON (CAMBRIAN)- PRECAMBRIAN UNCONFORMITY.

This description from Finks (1968m p.144). Walk to road-maintenance building at point where golf course is adjacent to the wooded ridge transecting the road. Walk northeast at base of ridge 25 feet to first

outcrops. The Lower Cambrian Hardyston Quartzite rests on light colored Precambrian gneiss. The Hardyston dips about 45 NW. The basal five feet or so of the Hardyston contains pebbles of quartz and fresh feldspar (!) up to an inch in diameter. About 20% of the pebbles are feldspar. PLEASE DO NOT HAMMER ON THIS OUTCROP. Exposures of the Cambrian-Precambrian unconformity are rare and should be preserved as an exhibit for students.

"The Hardyston probably is both alluvial and marine in origin. Poorly-sorted angular arkosic detrital material (represented by the lower part) formed an alluvial apron on the low-lying flank of a shield of Precambrian rocks (the Reading Prong). These deposits were partly reworked and augmented by better sorted orthoquartzite marine deposits (upper Hardyston) of an advancing Early Cambrian sea." (J.M. Aaron, 1969, p.21, in S. Subitzky, ed., Geology of Selected Areas in New Jersey and Eastern Pennsylvania: Rutgers Univ. Press, 382p.).

"The importance of this outcrop is to show that the Precambrian which was exposed at the surface at Newfoundland, during the Silurian, is still covered by the Cambrian at Franklin, only 10 miles to the west " (Finks, 1968, p.144).

90.5 Return to Fowler St. and turn right.

90.9 Turn left on Franklin Ave.

91.5 Jct. rte. 23 and Franklin Ave. LUNCH at Franklin Diner (or back a Franklin Pond park).

Turn left (north) on rte. 23.

92.4 Left on Walsh Rd. (opposite Hess station).

92.5 Park at the Ewald Gerstmann Private Museum, 14 Walsh Rd., Franklin, N.J. 07960.

STOP 5. GERSTMANN MUSEUM OF FRANKLIN-OGDENSBURG MINERALS.

Admission is free. This is probably the largest private collection of the Franklin mineral suite in the world. Mr. Gerstmann's collection emphasizes variations in crystals of mineral species. Thos stop is intended to familiarize you with the Franklin suite. Collectors (and Gertsmann still acquire material from the Trotter dump (STOP 7). Note the variations of franklinite, willemite,

zincite and rbodonite which you will soon collect. Much of the calcite and all of the willemite at the Trotter are fluorescent. Observe the fluorescent mineral display at the museum. Gerstmann will probably advise you that the best specimens are not found at the dump but in your laboratory after you get back and wash the specimens and observe them carefully. Also observe svabite, chondrodite and norbergite which occur at the Trotter.

92.8 Continue on Walsh, left turn at end onto Parker St., 3 blocks to Main St.; turn left on Main.

93.0 Turn left behind the Bank to the Trotter Mine dump.

STOP 7. TROTTER MINE DUMP.

Pay admission, normally $2.00. This is probably the best fluorescent mineral collecting locality in the world. Collect the zinc-manganese ores and other interesting specimens (up to 75lbs allowed). The Trotter mine shaft is flooded (can be observed from dump about 200 yards beyond gate). Observe and collect the camptonite dike referred to earlier; it is exposed in the eastern ravine (left as you walk in) about 200 yards be-yong the gate. Good collecting sites occur along path on west edge of property. Find something? It doesn't take long to catch Franklin fever.

133.0 Return to Rutherford via: (1) rte. 23 to U.S. 46 to rte. 3 (exit just beyond Passaic River bridge to Park Avenue, left onto Park to West Passaic Avenue, left four blocks to Fairleigh Dickinson University campus.); (2) rte. 23 to rte. 517 to rte. 15 to I 80 to rte. 3 (and local streets as in (1) above).

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Guidebook for Field Trips
Rutherford Meeting, 1972

FIELD TRIP NO. 5

CRETACEOUS AND TERTIARY GREENSANDS AND THEIR FAUNA, NEW JERSEY COASTAL PLAIN

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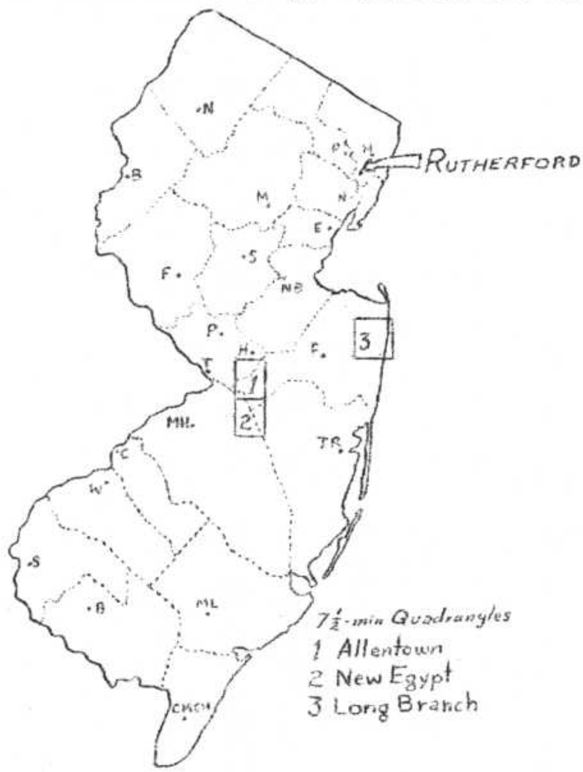


Prepared for the 1972 Meeting of the Eastern Section of the National Association of Geology Teachers
8 April 1972

Field Trip No. 5

Cretaceous and Tertiary Greensands and Their Fauna, New Jersey Coastal Plain

Preparation

Ours will be a model "soft rock" field trip, at least in that the materials we encounter will, most assuredly, be soft: a mason's hammer or small trowel will be all that is necessary to loosen samples. Bring also a field notebook, and bags and labels if you wish to keep specimens. Field clothing is necessary, and should include boots or shoes which can be subjected to muddy stream banks. An extra change of footwear might provide comfort on the return trip. Pack a lunch.

Geologic Setting

The coastal plain is a province of low relief lying along a continental margin between a higher, inland area (usually a mountain range) and the sea. The distinction between the Coastal Plain Province and the Continental Shelf is geologically of subsidiary importance, for the boundary between the two is the shoreline, which may migrate inland or seaward a rather great distance due to only a slight change in relative sea level. It is fair to speak of the Coastal Plain Province as the "emerged coastal plain", and the Continental Shelf as the "submerged coastal plain", for both are parts of a geologic unit sharing the same fundamental geologic characteristics and structural origin.

The sediments of the coastal plain are the youngest geosynclinal accumulations on the continent. They are varied, but are typical of miogeosynclinal deposits. Some are terrestrial, and some marine; the latter represent littoral to neritic bottom environments. Sands, silts, and clays are the commonest sediments in the New Jersey portion of the coastal plain. Carbonate constituents are generally minor here, though they are increasingly important farther south. Glauconite is abundant in the coastal plain beds, earning for some of them the antique term "greensands".

In New Jersey the oldest coastal plain beds are of Early Cretaceous age, and the first great sequence continues throughout the Eocene. A second major sequence represents the time from middle Miocene throughout Pliocene. Pleistocene and Holocene deposits comprise a third, very discontinuous and superficial veneer. All these relatively young, coastal plain sediments overlie with profound unconformity rocks of Precambrian, Early Paleozoic, and Triassic age. Though there is great structural complexity in these underlying, older rocks, as there is in the older rocks which everywhere bound the coastal plain on its landward margin, the rocks of the coastal plain have experienced only very gentle tectonism, and are practically undeformed. Beds dip homoclinally, the older formation more steeply than the younger. In the area, we will visit, the range in southeastward dip

is from 0.1° to 0.4°, which is too small to read with a Brunton compass, especially when bedding is indistinct and outcrops are small.

Taken as a whole, the coastal plain sediments form an undeformed package of seaward-thickening wedges, which apparently end somewhat abruptly at the shelf edge. We cannot look for their continuation on another continent, because all the coastal plain sediments are younger than the last opening of the Atlantic. The coastal plain beds end by "thickening out" at the very edge of the continent - any sediments carried beyond must end up on the continental slope or the abyssal plain. As Dietz has observed (most recently, 1972) coastal plains accumulate on the foundering trailing edges of continental plates. Thus, though themselves virtually devoid of scars of tedtonism, coastal plains are one of the most reliable continental indicators of plate movement.

Outcrops

Because the sediments of the coastal plain are largely underformed, they lie at very low dips, and provide only very gentle slopes for stream runoff. Consequent streams, those running down the dip direction of the beds, will necessarily have gentle gradients, and broad valleys. The great permeability of many coastal plain formations, and especially their soils, further diminishes the erosive effect of stream runoff. Later-formed, obsequent streams flow with a somewhat steeper gradient in a direction opposite dip: in New Jersey, this means into the Delaware River, or the Raritan by way of its tributaries. Obsequent streams such as Crosswick's Creek provides the best opportunities for natural outcrops in the New Jersey coastal plain. Unfortunately, the unconsolidated beds slump easily, and even very fine outcrops may disappear in a matter of years. For example, a favorite outcrop for collecting Marshalltown Formation fossils provided Weller (1907) and other early workers with cratefuls of specimens, but it is now impossible to tell which overgrown slope yielded the former bounty. The stream bank outcrops we do find today are often in small, rapidly cutting tributary branches, whose present erosive activity may be caused by increased runoff due to agricultural activity: so even some of our best "natural" outcrops may be manmade, at least indirectly. Coastal plain geologists here in New Jersey have by necessity relied heavily on marl pits, sand quarries, wells,roadcuts, auger holes, and other artificial exposures.

The outcrop pattern formed by coastal plain beds is simple, because of the homoclinal attitude, and consists of a series of bands trending along the northeast strike direction. Moving southeast (in the dip direction) across these outcrop bands, one encounters successively younger strata. The very low dip angles of the beds exaggerate the effect of stream dissection in complicating the fundamentally simple banded outcrop pattern.

Stratigraphy

It is fortunate that structure is simple in the coastal plain, for the stratigraphic problems are tricky enough as it is. One of the main difficulties is in identifying formations: beds of very similar lithology

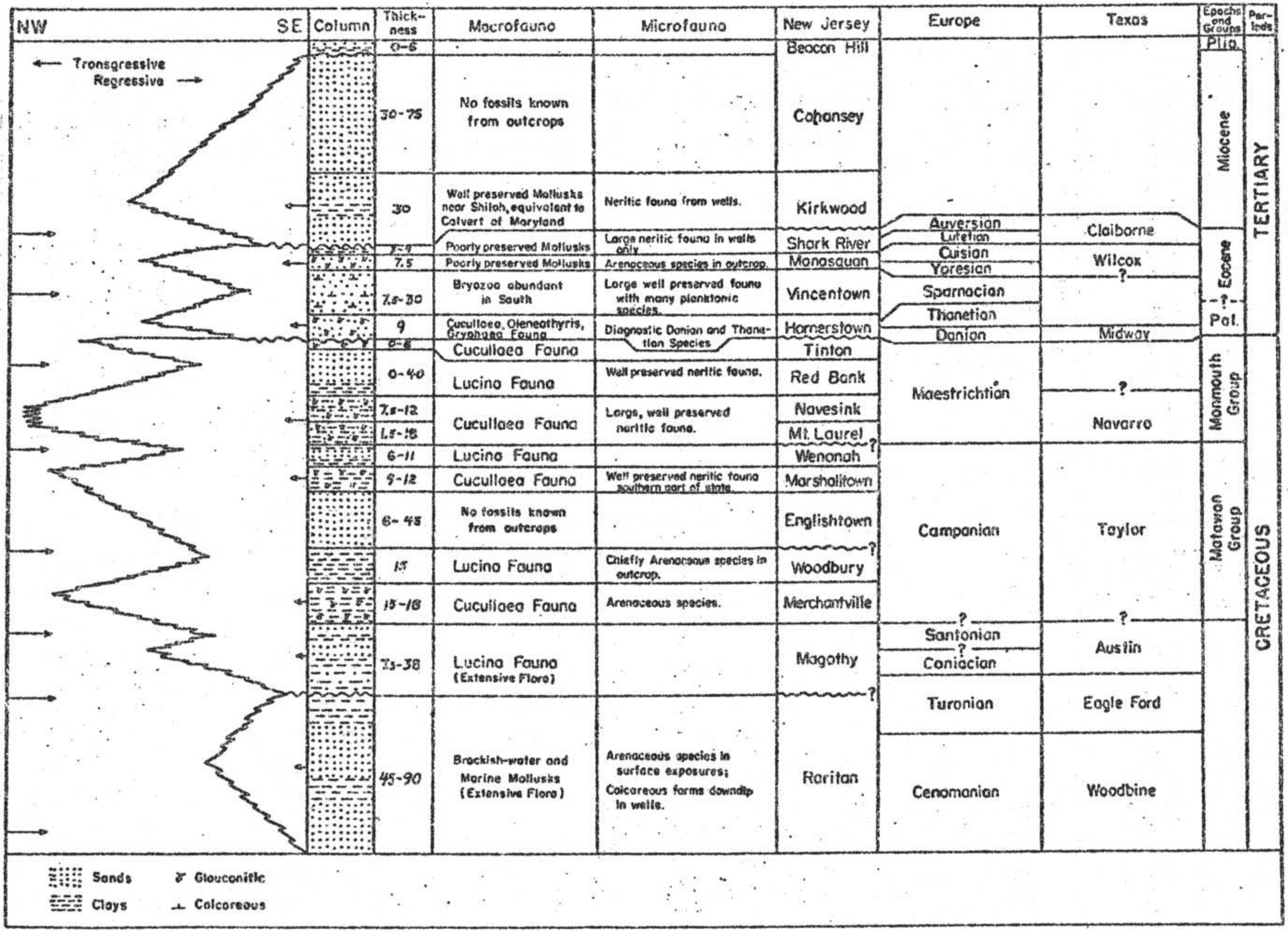


Figure 1 - Cretaceous and Tertiary Formations in the Coastal Plain of New Jersey

may belong to different formations. For example, we will see at least three glauconitic formations which are reliably distinguished in the field only by fossil content or position in the sequence. Boundaries between formations are often gradational, and breakes in deposition have sometimes left only subtle records. There are probably several minor disconformities which are not yet widely recognized.

The Cretaceous and Tertiary coastal plain formations of New Jersey are summarized in Figure 1 (slightly modified from Dorf and Fox, 1957). The occurrence of similar lithologies is a result of a number of transgressive-regressive cycles. There is also a corresponding recurrence in facies fossils. The glauconite-rich formations preserve a characteristic fauna designated the *Cucullaea* fauna, representing relatively deep water, offshore conditions. Glauconite-poor formations of clay and silt typically carry the so-called *Lucina* fauna, indicative of a nearshore, shoal water environment. The names of the two faunas are not the most felicitous, for neither *Cucullaea* nor *Lucina* are very commonly preserved; we may, nonetheless, mark a recurrent glauconite-facies fauna at the most transgressive phase of each cycle. Sedimentary processes or tectonic events are variously cited as causes for the observed cyclicity, but the cause is uncertain. It is obvious enough, though, that on a gently sloping shelf a rather small vertical influence can have great consequences in the lateral migration of environments. From the ideas of Dietz (1972), it might be predicted that periods of rapid seafloor spreading correspond to times of transgression on the coastal plain, but one hesitates to invoke continental drift as an explanation for everything.

Glauconite

One of the most distinctive features of our coastal plain deposits is the abundance of glauconite pellets, which in some formations make up more than 50% of the sediment. Nowhere in the world is glauconite now being deposited so widely and in such concentrations.

The material we call glauconite may vary somewhat in composition (Burst, 1958), but the typical glauconite of the New Jersey coastal plain is of rather uniform mineralogy (Light, 1952, p.74; Owens and Minard, 1960, p.43). Nevertheless, it occurs in sand-size pellets or grains of several distinctive shapes: a) ovoids and botrzoidal grains; b) very rarely as internal molds of foraminiferids; and c) as subcylindrical grains exhibiting marked parting perpendicular to the long axis of the grain. (The latter have been called "accordion" forms by Galliher (1935), "tabular" forms by Light (1952), "concentina" forms by Hutton and Seelye (1941), and apparently "caterpillar" forms by Warshaw (1957)).

Glauconite pellets may be light green to very dark green. Weathered glauconite beds turn rusty or reddish brown colors upon oxidation of the ferrous iron in the mineral. Glauconite pellets eventually disintegrate under normal subaerial weathering conditions, and thus cannot be reworked easily from terrestrial outcrops, except possibly in stream beds where erosion and redeposition occur very rapidly and the grains are protected from oxidation by the presence of water.

Several researchers have laid stress on the possible distinction between primary (authigenic)glauconite, and reworked (detrital) glauconite. Pettijohn, in the first edition of his "Sedimentary Rocks" (1949), says that "failure to make such a distinction has led to misconceptions concerning the genesis of glauconite", but this phrase is missing from his later editions. Light (1952) has attempted to distinguish authigenic and detrital glauconite, and his methods have been carried forward by Owens and Minard (1960), who conclude that glauconites with fine to medium grain sizes and large proportions of accordion forms are primary, but glauconites with coarse grain sizes and rounded forms have been reworked under marine conditions. Just how the reworking of these grains occurs such that the reworked grains are coarser than the original, primary grains, is difficult to imagine. That the accordion grains are fragile, and cannot have been transported far, has been noted by Minard and Owens (1962), and is cited as evidence for the authigenic origin of accordion shaped glauconite pellets. The rounded grains, however, may also be authigenic.

Perhaps consideration should be given to the physical difference between the rounded and the accordion glauconite pellets. Warshaw (1957) reports that the rounded glauconite grains consist of plates with random orientation. On the other hand, the parting characteristics of the accordion grains would appear to be a manifestation of a high degree of parallel alignment of constituent flakes or plates. Though we might expect accordion grains to be destroyed preferentially by aggitation, we would not expect the preferred internal alignment of flakes within the pellet to be randomized merely by the process of transportation; nor can we imagine the grain size increasing during a reworking process. In short, we are forced to conclude that both the rounded and the accordion grains may be primary, and that whatever process creates these pellets is able to produce some composed of well aligned glauconite mineral flakes, and others of randomly oriented flakes.

We are now led to a consideration of the origin of primary glauconite, a matter which has been discussed and reviewed at length (viz. articles by Cloud, 1955, and Pettijohn, 1957, among others). It seems probable that, although glauconite can form in a variety of ways, the typical, extensive, coastal plain glauconite beds consist of nothing more than altered fecal pellets of marine invertebrates. The possibility of a fecal origin for glauconites was recognized by Takahashi (1929; Takahashi and Yagi, 1929; and Takahashi, 1939), but is more forcefully and convincingly asserted by Stenzel, et.al. (1957, pp.30-31). The following lines of evidence support a fecal origin for coastal plain glauconites:

1) The size of the glauconite grains is within the size range of fecal pellets of marine invertebrates.
2) The form of many glauconite grains corresponds to the shape of known fecal pellets (see Moore, 1939, and references listed therein).
3) The distinction between rounded and accordion grains can be explained as a result of differences in the peristaltic movements of the alimentary tracts of various benthonic deposit feeders.

In very small deposit feeders, the surface area of the digestive tract is large relative to the volume of ingested mud, so a simple peristalsis need only move the material straight through, packing it tightly before ejection as fecal pellets. This tight, regular packing of tiny clay fragments produces the generally small, accordion grains which are characterized by a degree of internal alignment of flakes. The constituent flakes tend to line up, like leaves packed in a bushel basket, perpendicular to the direction of alimentary transport.

Larger deposit feeders, on the other hand, are confronted with a larger volume of ingested mud relative to the surface area of their larger-bore digestive tracts. More complex peristalsis is necessary in order to churn and mix up the ingested material for efficient digestion. The resulting larger pellets will therefore have a more random orientation of constituent flakes. The pellet shape will be rounded, or as interlayer expansion occurs, botryoidal.

4) The fecal origin of glauconite explains the otherwise paradoxical association of a rich benthonic fauna (requiring oxygenated bottom waters) with glauconite (which, according to Takahashi, 1939, Cloud, 1955, and others, requires a reducing environment for formation). Dr. H. B. Stenzel has pointed out to this writer that fecal pellets constitute mucous-packaged reducing microenvironments, and therefore are favorable sites for glauconite formation. Bottom water oxygen content may be sufficient for benthonic invertebrates, yet the fecal-rich sediments are maintained at reducing conditions by the addition of the organic detritus and clay in feces and pseudofeces of suspension-feeders, constantly reworked by the deposit-feeders.

5) The association of glauconites with environments of slow deposition is explained by the necessity for extended successive reingestion of fecal pellets by deposit feeders in order to produce glauconitization. If sedimentation is too rapid, deposit-feeders may not have enough time to expose the sediments to the reducing microenvironment of glauconitization.

6) The lack of well-developed bedding in glauconite beds explained as a result of extensive burrowing and homogenization by deposit-feeding invertebrates, the organisms largely responsible for glauconite pellet formation.

7) The observed stratigraphic range of glauconites, from Cambrian to Holocene (Pettijohn, 1957, p. 469), can be explained by the necessary part played in its formation by advanced benthonic organisms of Phanerozoic times.

Several important questions are still unanswered concerning glauconites. Marine geochemists and mineralogists must explain why glauconite is so abundant in the coastal plain Cretaceous and Cenozoic, yet is not forming abundantly today. Perhaps oceanic circulation was more restricted when the narrow proto-Atlantic first opened, and the bottom waters therefore had a different chemistry; or perhaps sea-floor spreading itself has effected the geochemistry of the shelf waters, possibly through some of the processes considered by Holland (1969, 1971).

If glauconite grains are fecal pellets, then they are at least partly in the province of paleoecology-paleontology, and researchers in this realm must further examine the dietary habits and pellet-forming abilities of deposit-feeders.

Paleontology

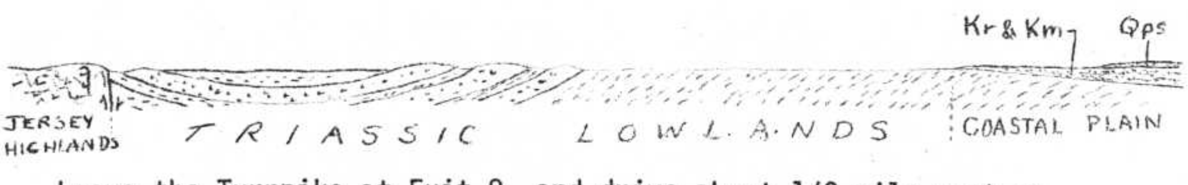
The fossil content of the beds we will visit is discussed under the heading of the various stops. A few generalizations may be made, however, about the preservation of fossils in the New Jersey coastal plain. Fossils are rare in many formations, and most often occur only as molds. Furthermore, our best localities for collecting generally yield preserved original shell material from only those organisms which produce calcite shells: these are primarily foraminiferids, brachiopods, oysters, scallop-relatives, anomias, and belemnites, and occasionally crab claws, bryozoa, and echinoids. Aragonite shell material is only very rarely found intact. Much of our bivalve and gastropod fauna is known only from poorly preserved molds, which are identified by comparision with whole specimens from such exceptional outcrops as the Ripley beds at Coon Creek, Tennessee. Though laboratory tests show the solubility of aragonite to be only slightly greater than calcite, in the geologic long run aragonite just does not last. If the aragonitic shell dissolves before the sediment around it lithifies slightly, then not even an imprint will remain. Remember that most of our coastal plain formations are scarcely lithified at all today: if it were not for the slightly different geochemical microenvironment (favoring lithification by iron oxides and glauconite) provided by the clams own shell cavity, molds of these animals would be even more uncommon. This explains why internal molds *(Steinkerne)* of clams are often easier to find than their external molds.

For identification of coastal plain fossils, the best general references are Richards, *et al.* (1958, 1962), and its predecessor, Weller and Knapp (1907). The older work has better illustrations, and (through a geological misunderstanding) includes with its Cretaceous fossils the Tertiary faunas we will see on this trip. For foraminiferids, see Cushman (1946), Hefker (1955), McLean (1952, 1953), Nine (1954), and Olsson (1960).

ROAD LOG

Drive south from the Rutherford Campus of Fairleigh Dickinson University to State Hwy. 3, and proceed east, following signs to the New Jersey Turnpike. At Secaucus, get on the Turnpike heading south. *We are now driving through the Hackensack Meadows. On our left (to the east) is the Palisades Diabase ridge and Jersey City and Bayonne; in the distance to the right are the Watchung Mountains, composed of basalt. We are in the Triassic Lowlands Province. About 2 1/2 miles south of the interchange, we pass on our right Laurel Hill, a diabase body related to the Palisades, just before crossing over the Hackensack River. About 2 more miles beyond we cross the Passaic River, and leave the main portion of the meadowlands. Newark Airport is passed on the right. About 2 miles south of Exit 12, we enter the Atlantic Coastal Plain Province. Between exits 11 and 10 we cross the terminal moraine of the Wisconsin glacier. South of the maraine we pass over sands and clays of the Cretaceous Raritan and Magothy formations, which are generally hidden by Pleistocene sands and gravels of the early glacial and interglacial Pensauken Formation. Shortly beyond Exit 8A, we travel over the oldest glauconitic beds in the coastal plain, the Merchantville Formation - which is unfortunately concealed here by the Pensauken Formation.*

FIGURE 2 - Relationship between Triassic Lowlands and Coastal Plain near Perth Amboy (vertical exaggeration x $2\frac{1}{2}$).



Leave the Turnpike at Exit 8, and drive about 1/2 mile west on State Hwy. 33 to the center of Hightstown. Follow signs for County Road 539 (South Main Street) heading south. We are now entering the area of the Allentown Quadrangle. On the outskirts of town, County Road 539 is called Old York Road, and about a mile south of town passes over the Turnpike. *Set trip mileage counter to zero at this point.*

0.0	0.0	Old York Road (County Road 539) passes over New Jersey Turnpike
0.4	0.4	Pass through Eiler's Corner (intersection). This land is underlain by the Cretaceous Englishtown Formation, a sandy unit which we will visit at our first stop.
1.9	1.5	Cross Assunpink Creek.
2.9	1.0	New Sharon, a small settlement.

4.5 1.6 New Canton

5.6 1.1 Center of Allentown

5.8 0.2 Cross Doctor's Creek just below Conine's Millpond.

6.2 0.4 Bear left at Y intersection

6.3 0.1 Intersection. Turn left (south) on Ellisdale Road.

7.7 1.4 Cross Pleasant Run, which cuts into the Englishtown Formation.

8.3 0.6 Triangle intersection.
Turn sharply left (east) on Extonville-Polhemustown R Road.

8.4 0.1 Pass Princeton Nurseries on left.

8.5 0.1 Pull off on right side of road near culvert. Walk into the woods, following the valley south for about 150 meters.

STOP 1

Excellent exposure of the Englishtwon Formation on the east bank of this tributary to Crosswick's Creek. "Quartz sand and clay; intercalated, thin bedded sequences of micaceous, feldspathic, quartz sand and clay and very micaceous silty clay" (Owen and Minard, 1966). Cross-bedding is clearly evident at this stop. The Englishtown Formation is overlain by Quatenary terrace gravels in this exposure, but the material higher in the bank, above the terrace level, is the Cretaceous Marshalltown Formation. Only a few poorly preserved fossils have been recovered from the Englishtown Formation in this area, and none are reported for this locality. A marine or marginal marine environment is represented by this formation, which contrasts markedly with the glauconite beds we will visit presently.
Return to cars, and proceed east on Polhemustown Road.

9.5 1.0 Park near house on left (Keller property; the dog, Max, is friendly). Walk 50 meters behind house to stream, another tributary to Crosswick's Creek.

STOP 2

A fine exposure of the Marshalltown Formation. "Quartz glauconitic sand, dark greenish gray where unweathered and grayish orange where weathered. Weathered exposures are commonly coated by yellow and white sulfate minerals (jarosite and gypsum).

Mostly a massive bedded, poorly to moderately sorted very silty fine grained sand..." (Owens and Minard, 1966). The jarosite is probably a weathering product of glauconite, for jarosite has been found in the center of weathering glauconite grains from the Miocene of Martha's Vineyard (Clancy, 1971) Gypsum is here also a soil product, possibly reflecting the presence of calcium carbonate and pyrite in the unweathered material.
Not far downstream from the house is a small waterfall developed on a more resistant ledge in the formation. The ledge corresponds to a burrowed zone visible just upstream from the waterfall. The burrows are orange, and some stand out quite clearly. It is possible that the burrowed zone has been hardened by B-zone cementation, due to its slightly higher porosity. Macrofossils (other than burrows) have not been found here. There is a possibility that microfossils may be present, since they become abundant along strike to the southwest (Mello, Minard, and Owens, 1964). At the least, you will find here a good sample of accordion type glauconite pellets.
Return to cars, and proceed east on Polhemustown Road.

9.8 0.3 Intersection; turn right (south) on Hill Road (Walnford Road).

10.2 0.4 Pull off to right by electric fence. Get out and carefully crawl under fence and scramble down to stream cut just 10 meters west of road.

STOP 3

Marshalltown Formation. We will look for evidence of burrowing, which has not yet been reported at this locality.
Return to cars and proceed south.

10.5 0.3 Cross Crosswick's Creek at Walnford, site of an early mill. Bear left after bridge, and continue south up a hill slope which is underlain successively by the Cretaceous Wenonah, Mt. Laural, and Navisink formations. We now enter the area of the New Egypt Quadrangle. Road crosses several small valleys cut by tributaries to Crosswick's Creek, which lies to the east (left) of us. Also to our left we will be passing two classic Navisink fossil localities described by Dorf and Fox (1957) and known as the Nutt farm localities. Both are highly fossiliferous and are of great stratigraphic interest. Over-visitation, by busloads of poorly supervised beginning students, along with worry

over legal liability for accident, has caused the present owner to ban field trips to his property.

12.9 2.4 Intersection. Turn left (east) on Arneytown-Hornerstown Road

13.2 0.3 Recross Crosswick's Creek, and park off left side of road by ruins of burned-out house. Walk about 300 meters north (downstream) along east bank of Crosswick's Creek to outcrop.

STOP 4

This outcrop exhibits 10 meters of section including the gradational contact between the Navisink Formation and the lower member of the Red Bank Formation. The Navisink Formation is "a medium- to coarse-grained, clayey, quartz-glauconite sand... Near the top, the Navisink is a grayish-black, medium-grained, micaceous (muscovite and chloritized mica), clayey, glauconite sand containing a few quartz grains." The lower member of the Red Bank Formation "consists of a clayey, very micaceous, glauconite sand... that contains minor amounts of quartz..." (Minard and Owens, 1962). A few fossils are to be found at this stop: they are all molds, with no original shell material intact. A recent visit yielded the bivalves *Exogyra*, *Pycnodonte* and *Cucullaea*. Glauconite grains here are of the larger, rounded variety, thought by some to be detrital.
Return to cars and continue east toward Hornerstown.

14.9 1.7 Center of Hornerstown. Bear left on Meirs Road.

15.2 0.3 Intersection. Turn sharply right (southeast) on County Road 539.

15.4 0.2 Pull off on right side of road just beyond bridge. Walk west to pit.

STOP 5

This is the type locality of the Hornerstown Formation. of Paleocene age. "The Hornerstown sand is a nearly pure glauconite sand throughout much of its thickness and lateral extent. It is massive, dusky-green, clayey, medium to coarse grained, and contains a few conspicuous milky quartz granules and fine to coarse grains. The glauconite grains are rounded, and the lack of delicate forms, such as accordion forms suggests reworking" (Minard and Owens, 1962). Though reported as unfossiliferous by Dorf and Fox (1957, p. 23), this locallity yielded skark teeth and reptilian bone fragments in the early 1960's.
Return to cars and continue southeast on County Road 539.

15.7 0.3 Intersection. Turn right (southeast) on County Road 537.

17.5 1.8 Intersection. Turn right (north) on Allentown-New Egypt Road for optional stop (if time allows).

17.9 0.4 Pull off road south of small bridge. Walk west about 200 meters along north bank of "Contact Creek" (Dorf and Fox, 1957, p. 23).

STOP 6 (optional stop, if time permits)

Contact between 1.2m of the lower member of the Red Bank Formation (black, micaceous, sandy, glauconitic clay, containing fragments of the Cretaceous ammonite *Sphendiscus* and casts of *Cuculleaea)* and 1.5m of the overlying Hornerstown Formation (glauconite sand of Paleocene age, containing in its basal 0.5m reworked fragments from the Red Bank Formation).
Return to cars and turn about, heading south on the Allentown-New Egypt Road.

18.3 0.4 Intersection with County Road 537. Continue straight.

18.8 0.5 Pull off onto shoulder on right side of road. Walk about 200 meters west across cornfield and into woods.

STOP 7

Here a tributary to Crosswick's Creek exposes the contact between the Hornerstown and Vincentown formations in a 2m waterfall. *This outcrop is very unusual, and collecting from the waterfall itself is to be discouraged. Better specimens of the same material may be more easily obtained at the next stop. Take pictures.* At the base of the waterfall the Hornerstown is a dark, almost black glauconite sand containing abundant shells of *Pycnodonte dissimilaris*. Upward toward the lip of the waterfall the grains become coarser, and quartz predominates: this is the topmost part of the Hornerstown, and it contains a densely packed bed of the terebratulid brachiopod *Oleneothyris harlani*. Evidently an environmental change occurred, reflected in the coarsening of the sediment and the decrease of glauconite as well as the faunal change. At the next stop we will discuss the adaptations of *Pycnodonte* and *Oleneothyris* to their respective substrates.
Return to cars and continue south on the Allentown-New Egypt Road, which in New Egypt becomes Evergreen Road.

19.7	0.9	Intersection with Main Street in the town of New Egypt. Turn right (left).
19.9	0.2	Bear right at fork on Jacobstown Avenue.
20.4	0.5	Turn right (north) on dirt road.
20.8	0.4	Bear right at farmhouse and park cars. Walk about 300 meters northeast to woods and descend to stream.

STOP 8

Another tributary to Crosswick's Creek provides a better spot for collecting the fauna of the Hornerstown-Vincentown contact. *Oleneothyris harlani* is especially abundant, and broken specimens even form point bar deposits in the stream bed.
The mode of life of oysters such as *Pycnodonte dissimilaris* is described at length by Stenzel (1971, pp. 1072-1076). The gryph-shaped (hooked, or gryphaeiform oysters) are adapted for life in a soft, somewhat yielding ooze, in which they floated with the convex left valve acting as the hull of a boat. In this position the commissure (opening) of the valves was held above the level of the sediment, so that the oyster could carry on its suspension-feeding activity without fouling its delicate gill mechanism with substrate mud. The young *Pycnodonte,* like most "normal" oysters, required a hard substrate, and would attach itself to any small, hard object available, or even to a stem of algae. The left valve, near the beak, often bears a scar of this youthful attachment. As the size of the *Pycnodonte* increased, however, it outgrew the small chunk of hard substrate, and tumbled over, left valve underneath, into its adult position (Figure 3). The left valve of *Pycnodonte* is very heavy, like the weighted keel of some ships, to ensure that the oyster maintains its proper orientation. The right valve, on the other hand, is built as light as possible using the vesicular shell structure characteristic of the Subfamily Pycnodonteinae.
The *Pycnodonte* we fine here are not in growth position, though we can find them in proper orientation with both valves together at other outcrops. It appears that this oyster bed (best seen at the previous stop) is actually a condensed accumulation, brought about by winnowing of the fine glauconite matrix. The environment was changing: the sea bottom was influenced much more by wave and current action. This change favored the growth of the *Oleneothyris harlani* brachiopod we find overlying the oysters. Because brachiopod pedicles do not fossilize, it is impossible to tell exactly how this terebratulid was attached to the sediment, but the large, open foramen indicates a substantial hold on the

substrate. It is very likely (and almost a necessity in coarse, sandy material) that this brachiopod had a rootlike, digitate pedicle, as do some living terebratulids (Williams and Rowell, in Moore, ed., 1965, p. 15). Many of the brachiopods in this biostrome are broken (the anterior portion being torn away), and even many whole specimens are jumbled together: burial position and condition here bespeak current action. We may imagine a current-swept bottom, almost an environment of marine planation, with a dense population of *Oleneothyris* tending to prevent further erosion of the sea bottom, or in places armoring the bottom with dead shells.

Broken pedicle valves of *Oleneothyris harlani*, such as those picked up from the stream bed at this locality, exhibit a very dense layer of secondary shell material (to 8mm thick) filling much of the posterior portion of the valve beneath and lateral to the hinge teeth (see Figure 4a). Considering that the viscera of a brachiopod also occupy the posterior portion of the shell cavity, it is evident that the center of gravity of this species in life must have been well toward the posterior end. The great deposits of shell material made the shell too heavy to be supported above the substrate, but (like the thick left valve of *Pycnodonte)* they acted to keep the shell in proper orientation for feeding. (Figure 4b).

Return to cars and drive out dirt road to Jacobstown Avenue.

21.2	0.4	Turn left (east) on Jacobstown Avenue, which runs into Main Street in New Egypt.
21.9	0.7	Turn left (north) on Evergreen Road.
23.2	1.3	Intersection with County Road 537. Turn right (northeast). We leave the area of the New Egypt Quadrangle.
41.3	18.1	Center of town of Freehold. Continue on County Road 537.
41.6	0.3	Fork. Bear right on County Road 537 toward Colt's Neck.
47.0	5.4	Colt's Neck. Continue straight (east) on County Road 537. We enter the area of the Long Branch Quadrangle.
50.9	3.9	County Road 537 ends. Turn left (north) on Swimming River Road.

FIGURE 3

Schematic history of substrate relationships of Pycnodonte. Drawings are not to scale.

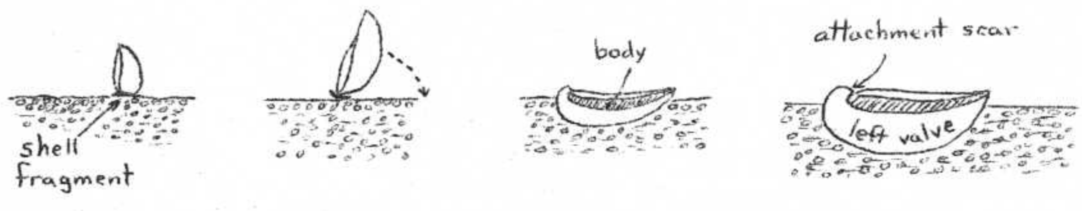


FIGURE 4

Posterior portion of pedicle valve of *Oleneothyris harlani*, showing ballast of secondary shell material and its influence on the life position of this terebratulid.

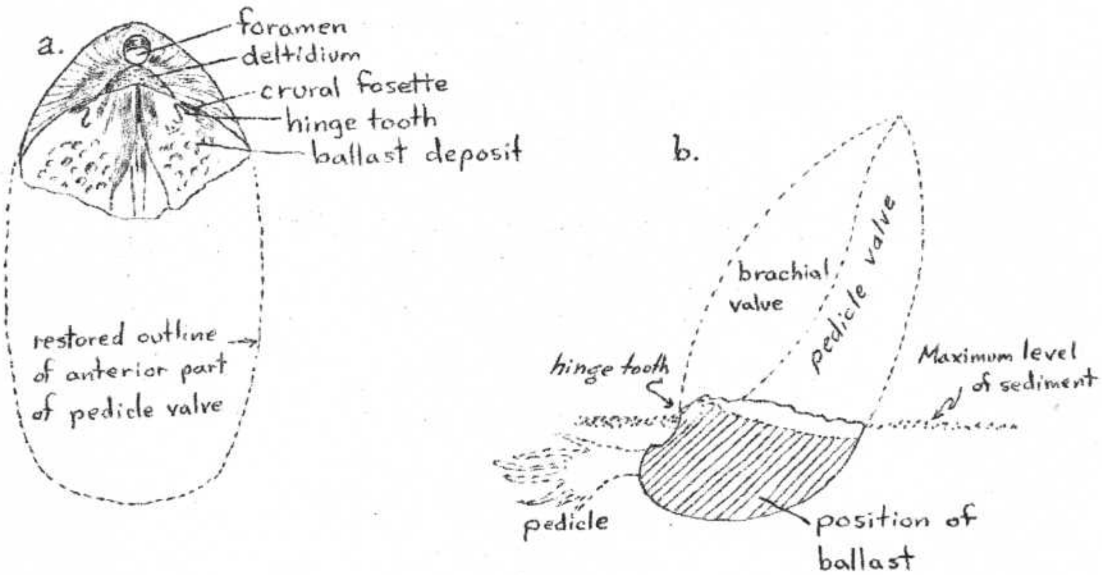
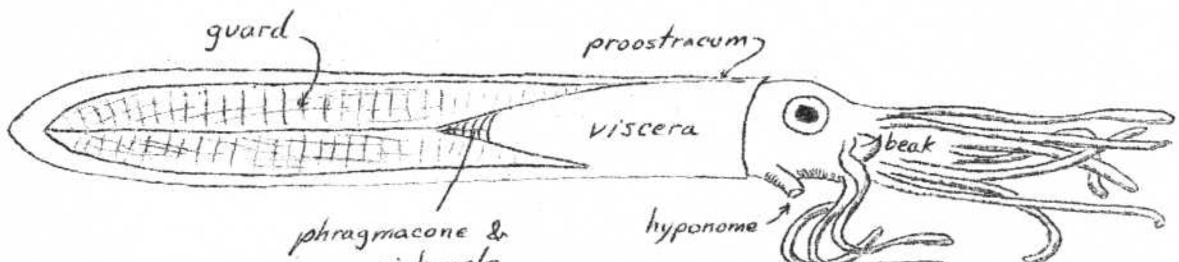


FIGURE 5

Restoration of *Belemnitella*. The guard is normally preserved.



52.8	1.9	Intersection at Lincroft. Continue straight on Middletown-Lincroft Road (County Route 50).
54.7	1.9	Cross under Garden State Parkway.
55.5	0.8	Intersection with Nut Swamp Road. Continue straight.
55.7	0.2	Road descends to bridge crossing Poricy Brook. Park on right side of road just beyond bridge and adjacent to construction site. Walk downstream 100 meters to outcrops on southwest side of brook.

STOP 9.

The bank here exposes 4.5m of Navisink Formation (greenish-black clayey glauconite sand) containing shell beds of *Exogyra, Pycnodonte, Agerostrea, Choristothyris,* and *Belemnitella*. Above the Navisink is 7.5m of the lower member of the Red Bank Formation (similar to that seen at Stop 4). The upper part is weathered to brown; the lower part is dark gray.

Note that all the common fossils here are calcite. Aragonite-shelled mollusks, such as *Cardium* sp., leave only Steinkerne. The gryph-shaped oyster *Pycnodonte convexa* (possibly = *P. vesicularis* of Europe), is abundant. Many specimens possess a well-defined posterior flange (the "posterior auriculation" of Weller, 1907), which Stenzel (1971, p. 1019) interprets as the "growth track of the successive positions the exhalant pseudosiphon occupied during the growth of the animal". Also note the presence of the *Exogyra* oysters, who dealt with the problem of soft substrates by a strategy very similar to that employed by *Pycnodonte*. The small, crescentic oysters (*Agerostrea)* apparently used extreme plication of the shell margin to restrict entry of sediment particles (Stenzel, 1971, pp. 1025-1026). *Belemnitella americana* was a squid-like, nektonic cephalopod, restored in Figure 5.

Return to cars and turn around, heading south on Middletown-Lincroft Road.

58.6	2.9	Intersection at Lincroft. Turn left (east) on Newman Springs Road.
59.8	1.2	Intersection with Garden State Parkway. Take northbound lane. Leave Long Branch Quadrangle.

104.2	44.4	Exit 153 (Clifton). Leave Parkway and go east on State Hwy. 3.
107.6	3.4	Cross Passaic River. Turn left (north) on Riverside Avenue.
108.4	0.8	Turn right (east) on W. Passaic Avenue. Four blocks down on the left is the Rutherford Campus of Fairleigh Dickinson University.

GOOD NIGHT !

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ERRATA

Page 5-1, bottom, for "the older formation", read "the older formations".

Page 5-5, Figure 1, thicknesses are given in meters.

Page 5-6, under Glauconite, for "botrzoidal", read "botryoidal".

Page 5-6, bottom, for "concentina", read "concertina".

Page 5-9, bottom, for "Hefker", read "Hofker".

Page 5-11, center, for Englishtwon", read "Englishtown".

Page 5-11, center, for "Quatenary" read "Quaternary".

Page 5-13, bottom, for "locallity yielded skark teeth", read "locality yielded shark teeth".

Page 5-14, under Stop 6, for *"Sphendiscus"*, read *"Sphenodiscus"*; for *"Cuculleaea"*, read *"Cucullaea"*.

Page 5-15, bottom, for "(hooked, or gryphaeiform oysters)", read "(hooked, or gryphaeiform) oysters".